ORDER

6580.5

INCLUDES CHG 1-6

MAINTENANCE OF REMOTE COMMUNICATION FACILITY (RCF) EQUIPMENTS

OCTOBER 16, 1989

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

Distribution: Selected Airway Facilities Field and Regional Offices, ZAF-600

Initiated By: ASM-156

CHANGE

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

6580.5 CHG 1

3/29/90

SUBJ: MAINTENANCE OF REMOTE COMMUNICATION FACILITY (RCF) EQUIPMENTS

1. PURPOSE. This change incorporates revised periodic maintenance intervals for hf, uhf, and vhf transmitters and receivers to correlate with the certification requrements of other handbooks.

2. DISPOSITION OF TRANSMITTAL. Retain this transmittal.

PAGE CONTROL CHART

Remove Pages	Dated	Insert Pages	Dated
v thru viii	10/16/89	v	10/16/89
		vi	3/29/90
		vii	3/29/90
		viii	10/16/89
77 thru 82	10/16/90	77 thru 82	3/29/90

Charles E. Gage for
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Distribution: Selected Airway Facilities Field and Regional Offices, ZAF-600

Initiated By: ASM-640

ASE-620

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

CHANGE

6580.5
CHG 2

5/29/92

SUBJ: MAINTENANCE OF REMOTE COMMUNICATION FACILITY (RCF) EQUIPMENTS

1. PURPOSE. This change incorporates revised periodic maintenance intervals for remote communications outlet class 0 (RCO-0) and remote transmitter/receiver class 0 (RTR-0) transmitters and receivers to correlate with the certification requirements of other handbooks. CCD No. N13655, Update Handbook Order 6580.5, Maintenance of Remote Communication Facility (RCF) Equipments.

2. DISPOSITION OF TRANSMITTAL. Retain this transmittal.

PAGE CONTROL CHART

Remove Pages	Dated	Insert Pages	Dated
iii and iv	10/16/89	iii	5/29/92
		iv	10/16/89
11 and 12	10/16/89	11	10/16/89
		12	5/29/92
79 thru 82	3/29/90	79 and 80	5/29/92
		81	3/29/90
		82	5/29/92
93 and 94	10/16/89	93	10/16/89
		94	5/29/92
103 and 104	10/16/89	103	5/29/92
		104	10/16/89
Appendix 8			
3 thru 6	10/16/89	3	5/29/92
		4	10/16/89
		5	5/29/92
		6	10/16/89

Charles E. Boyd for
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Distribution: Selected Airway Facilities Field and Regional Offices, ZAF-600

Initiated By: ASM-640

CHANGE

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

6580.5
CHG 3

9/28/93

ASE-620

SUBJ: MAINTENANCE OF REMOTE COMMUNICATION FACILITY (RCF) EQUIPMENTS

1. PURPOSE. This change establishes standards and tolerances and preventative maintenance activities for the Motorola UHF and VHF transmitters and receivers. This directive implements Configuration Control Decision (CCD) N15764, Update Order 6580.5 to Include Motorola TX and RX's.

2. DISTRIBUTION. This directive is distributed to selected offices and services within Washington headquarters, regional Airway Facilities divisions, the FAA Technical Center, the Mike Monroney Aeronautical Center, and Airway Facilities field offices having the following facilities/equipment: AFSS, ARTCC, ATCT, EARTS, FSS, MAPS, RAPCO, TRACO, IFST, RCAG, RCO, RTR, and SSO.

3. DISPOSITION OF TRANSMITTAL. Retain this transmittal.

PAGE CONTROL CHART

Remove Pages	Dated	Insert Pages	Dated
iii	5/29/92	iii	5/29/92
iv	10/16/89	iv	9/28/93
v	10/16/89	v and vi	9/28/93
vi	3/29/90		
xiii and xiv	10/16/89	xiii	10/16/89
		xiv	9/28/93
49 thru 52	10/16/89	49	10/16/89
		50	9/28/93
		51	10/16/89
		52	9/28/93
		52-1 thru 52-4	9/28/93
69 and 70	10/16/89	69	10/16/89
		70	9/28/93
75(and 76)	10/16/89	75 and 76	9/28/93
		76-1 and 76-2	9/28/93
79 and 80	5/29/92	79 and 80	9/28/93
81	3/29/90	81	9/28/93
82	5/29/92	82	5/29/92

Donald C. Campbell for
Charles L. Stith
Director, Operational Support Service

Distribution: Selected Airway Facilities Field and Regional Offices, ZAF-600

Initiated By: AOS-240

CHANGE

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

6580.5
CHG 4

2/2/95

SUBJ: MAINTENANCE OF REMOTE COMMUNICATION FACILITY (RCF) EQUIPMENTS

1. PURPOSE. This directive transmits revised pages to extend maximum allowable periodic maintenance intervals. Field offices will retain the control of determining their minimum maintenance intervals. This directive implements Configuration Control Decision (CCD) N17477, Extend Certification and Maintenance Intervals for Maintenance Handbooks.

2. DISTRIBUTION. This directive is distributed to selected offices and services within Washington Headquarters, regional Airway Facilities divisions, the FAA Technical Center, the Mike Monroney Aeronautical Center, and Airway Facilities field offices having the following facilities/equipment: AFSS, ARTCC, ATCT, EARTS, FSS, IFST, MAPS, RAPCO, RCAG, RCO, RTR, SSO and TRACO.

3. BACKGROUND. In January 1994, a National Quality Effectiveness Team (NQET) recommended to the Associate Administrator for Airway Facilities (AAF-1) that all national standard maintenance procedures and intervals be revalidated with the goal being a reduction in required maintenance activities and extending the periodicity of intervals. The team's recommendation was subsequently endorsed resulting in these changes.

4. DISPOSITION OF TRANSMITTAL. Retain this transmittal.

PAGE CONTROL CHART

Remove Pages	Dated	Insert Pages	Dated
v and vi	9/28/93	v	9/28/93
		vi	2/2/95
79 and 80	9/28/93	79 and 80	2/2/95

David E. Campbell for
James L. Hevelone
Acting Director, Operational Support

Distribution: Selected Airway Facilities Field and Regional Offices, ZAF-600

Initiated By: AOS-220

CHANGE

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

6580.5
CHG 5

10/23/95

SUBJ: MAINTENANCE OF REMOTE COMMUNICATION FACILITY (RCF) EQUIPMENTS

1. PURPOSE. This change establishes standards and tolerances and preventative maintenance activities for the Motorola UHF and VHF Linear Power Amplifiers (LPA). This directive implements Configuration Control Decision (CCD) No. N17824, Update Maintenance Handbook 6580.5, Maintenance of Remote Communication Facility (RCF) Equipments to include Motorola Linear Power Amplifiers.

2. DISTRIBUTION. This directive is distributed to selected offices and services within the Washington headquarters, the FAA Technical Center, the Mike Monroney Aeronautical Center, regional Airway Facilities divisions, and Airway Facilities field offices having the following facilities/equipment: AFSS, ARTCC, ATCT, EARTS, FSS, MAPS, RAPCC, TRACO, IFST, RCAG, RCO, RTR, and SSO.

3. DISPOSITION OF MATERIALS. Retain this transmittal.

PAGE CONTROL CHART

Remove Pages	Dated	Insert Pages	Dated
iii	5/29/92	iii	5/29/92
iv	9/28/93	iv	10/23/95
52-3 and 52-4	9/28/93	52-3 and 52-4	10/23/95
69	10/16/89	69	10/16/89
70	9/28/93	70	10/23/95
76-1 (and 76-2)	9/28/93	76-1 (and 76-2)	10/23/95

James H. Pritchard

for George W. Terrell
Program Director for Operational Support

Distribution: Selected Airway Facilities Field and Regional Offices, ZAF-604

Initiated By: AOS-220

CHANGE

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

6580.5
CHG 6

4/18/96

RECEIVED

LOAN COPY

SUBJ: MAINTENANCE OF REMOTE COMMUNICATION FACILITY (RCF) EQUIPMENTS

1. PURPOSE. This directive transmits revised pages to change the scope and coverage for joint use facilities and periodic maintenance for receivers. This directive implements Configuration Control Decision (CCD) No. N10602, A/G Radio PM at Joint Use Sites.

2. DISTRIBUTION. This directive is distributed to selected offices and services within Washington headquarters, the FAA Technical Center, the Mike Monroney Aeronautical Center, regional Airway Facilities divisions, and Airway Facilities field offices having the following facilities/equipment: AFSS, ARTCC, ATCT, EARTS, FSS, IFST, MAPS, RAPCO, RCAG, RCO, RTR, SSO and TRACO.

4. DISPOSITION OF TRANSMITTAL. Retain this transmittal.

PAGE CONTROL CHART

Remove Pages	Dated	Insert Pages	Dated
1 and 2	10/16/89	1 and 2	4/18/96
79 and 80	2/2/95	79	2/2/95
		80	4/18/96

Charles B Ochoa

George W. Terrell
Program Director for Operational Support

...NT CONTROL CENTER

Distribution: Selected Airway Facilities Field and Regional Offices, ZAF-600

Initiated By: AOS-260

FOREWORD

1. PURPOSE.

This handbook provides guidance and prescribes technical standards and tolerances, and procedures applicable to the maintenance and inspection of remote communication facility (RCF) equipment. It also provides information on special methods and techniques that will enable maintenance personnel to achieve optimum performance from the equipment. This information augments information available in instruction books and other handbooks, and complements Order 6000.15A, General Maintenance Handbook for Airway Facilities.

2. DISTRIBUTION.

This directive is distributed to selected offices and services within Washington headquarters, the FAA Technical Center, the Mike Monroney Aeronautical Center, regional Airway Facilities divisions, and Airway Facilities field offices having the following facilities/equipment: AFSS, ARTCC, ATCT, EARTS, FSS, MAPS, RAPCO, TRACO, IFST, RCAG, RCO, RTR, and SSO.

3. CANCELLATION.

This order cancels Orders 6600.22A, Maintenance of Point-to-Point and Air-Ground Communication Transmitting and Receiving Equipment, and 6630.2A, Maintenance of Communication Antennas and Transmission Lines.

4. MAJOR CHANGES.

This handbook revises, updates, and combines the information previously contained in three orders: Order 6600.22A, Maintenance of Point-to-Point and Air-Ground Communication Transmitting and Receiving Equipment; Order 6630.2A, Maintenance of Communication Antennas and Transmission Lines; and canceled Order 6520.4A, Maintenance Concept for Remote Transmitter/Receiver Class O (RTR-O) and Remote Communications Outlet Class O (RCO-O) Facilities. (Order 6520.4A was canceled by the directives checklist WA 0000.4G.)

5. MAINTENANCE AND MODIFICATION POLICY.

a. Order 6000.15A, this handbook, and the applicable equipment instruction books shall be consulted and used together by the maintenance technician in all duties and activities for the maintenance of remote communication facilities. The three documents shall be considered collectively as the single official source of maintenance policy and direction authorized by the Systems Maintenance Service. References located in the chapters of this handbook entitled Standards and Tolerances, Periodic Maintenance, and Maintenance Procedures shall indicate to the user whether this handbook and/or the equipment instruction books shall be consulted for a particular standard, key inspection element or performance parameter, performance check, maintenance task, or maintenance procedure.

b. Order 6032.1A, Modifications to Ground Facilities, Systems, and Equipment in the National Airspace System, contains comprehensive policy and direction concerning the development, authorization, implementation, and recording of modifications to facilities, systems, and equipment in commissioned status. It supersedes all instructions published in earlier editions of maintenance technical handbooks and related directives.

6. FORMS LISTING.

a. Use FAA Form 6600-6, Technical Performance Record, VHF/UHF Air/Ground Receivers/Transmitters, to record the performance of very-high-frequency (vhf) and ultra-high-frequency (uhf) transmitters, receivers, and transceivers. This form is available under NSN 0052-00-874-2000, unit of issue: PD.

b. Use FAA Form 6610-1, Technical Performance Record, SSB-AM Transmitter, High Frequency Point-to-Point/Broadcast, to record the performance of transmitters using the 3MHz-to-30MHz frequency band. This order form is available under NSN 0052-00-874-0000, unit of issue: PD.

c. Use FAA Form 6620-1, Technical Performance Record, SSB-AM Receiver, High Frequency Point-to-Point/Broadcast, to record the performance of receivers using the 3MHz-to-30MHz frequency band. This form is available under NSN 0052-00-874-1000, unit of issue: PD.

d. Use FAA Form 6000-8, Technical Performance Record–Continuation or Temporary Record/Report Form, to record miscellaneous performance information prescribed in chapter 4 of this order, for transmitters, receivers, transceivers, or ancillary equipment. This form is available under NSN 0052-00-686-0001, unit of issue: PD.

e. Use FAA Form 6050-3, Frequency Interference Report, when needed. This form is available under NSN 0052-00-837-1000, unit of issue: SE.

7. RECOMMENDATIONS FOR IMPROVEMENT. Preaddressed comment sheets are provided at the back of this handbook in accordance with Order 1320.40B, Expedited Clearance Procedures for Airway Facilities Maintenance Directives. Users are encouraged to submit recommendations for improvement.

David S. Yaeger

for W. Peter Kochis
Director, Systems
Maintenance Service

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CHAPTER 1. GENERAL INFORMATION AND REQUIREMENTS

1. OBJECTIVE.

This handbook provides the necessary guidance, to be used in conjunction with information available in instruction books and other handbooks, for the maintenance of remote communication facility (RCF) equipment.

2. SCOPE AND COVERAGE.

a. Remote communication facilities (RCF's) are consolidated networks of radio communication equipment, including antennas and transmission lines, that serve the combined needs of en route air traffic control, terminal air traffic control, and automated flight service stations. This handbook covers radio transmitters and receivers, with their associated antennas and transmission lines, operating in the vhf, uhf, and hf bands for agency air-to-ground (a-g) and point-to-point (PTP) data and voice communications. Some system concepts are included, primarily for hf facilities. System information for the vhf and uhf equipment is contained in Order 6480.6B, Maintenance of Terminal Air-to-Ground (A-G) Communication Facilities, Order 6490.1A, Maintenance of Flight Service Station (FSS) Air-to-Ground Communication Facilities, and Order 6470.29A, Maintenance of En Route Air-to-Ground Communications Facilities. To avoid repetition of standards and tolerances, periodic maintenance, and maintenance procedures, the three system handbooks listed above refer to, but do not duplicate, equipment * data contained in chapters 3, 4, and 5 of this order. Chapter 1, paragraph 8 of Orders 6470.29A and 6480.6B contains guidance concerning use of inadvertent conflicting or redundant handbook information or instructions. The maintenance requirements of this order do not apply to USAF radios located at joint use (FAA/USAF) facilities. Air Force technical orders, directives, and procedures contain requirements for USAF receivers.

b. Approaching obsolescence makes it necessary to omit certain older equipment items from discussion in this order. Programmed replacement items are either already covered by this order or will be accommodated by revision at a future time. For the interim period, field organizations are en- * couraged to issue supplements in accordance with the latest edition of Order 1320.1, FAA Directives System, for any additional coverage deemed essential for the older equipment items. On the other hand, if the regional Airway Facilities (AF) divisions believe national guidance through this order is required, they should submit their recommendations for coverage of standards and tolerances, periodic maintenance, and * maintenance procedures to be included to AOS-200, National Airway Systems Engineering Division. *

c. The Backup Emergency Communication (BUEC) System and National Radio Communication System (NARACS) are not included in this handbook. These equipments are covered in other directives.

3. AIRCRAFT ACCIDENT.

* The National Airspace System Operations is responsible for the * evaluation and documentation of the technical performance of facilities that were, or might have been, involved in an aircraft accident. This requires that facility operational data be obtained and recorded in the maintenance logs and performance record forms. These recorded data are official documents and may be used by an aircraft accident investigation board to determine the facility operational status at the time of the accident. To avoid any misinterpretation of the data, the entries shall be complete, clear, concise, and accurate. Order 8020.11, Aircraft Accidents and Incidents -- Notification, Investigation, and Reporting, should be consulted for details. The following steps must be accomplished and the results recorded for any RCF radio communication facilities involved in an aircraft accident.

a. No equipment adjustments are to be made until the as-found readings are recorded and after the flight check, if required, is accomplished.

b. Check the operating equipment record to ascertain whether there has been a changeover in equipment. If a changeover has occurred, both sets of equipment must be checked.

* c. Record all meter readings as found, but make no adjustments until after required flight inspection actions are completed.

d. Check voice modulation level.

e. Certify the meter readings and the log entry. Also have another technician or the supervisor certify the log entry.

f. Note any abnormal conditions, such as snow or ice on antennas or insulators.

g. If a check of the engine generator elapsed-time meter indicates that the generator has operated since the last visit, determine that the engine generator will start and run on a no-load test run. As soon as practicable, a full-load test shall be made and all meter readings recorded.

4. RECEIVER SENSITIVITY AND TRANSMITTER POWER OUTPUT ADJUSTMENT POLICY.

* The basic policy of Operational Support advocates standardization in system adjustment and performance. However, operational requirements and environmental factors can impose constraints that demand deviation from system equipment standards. This paragraph contains policy guidance relating to the operational setting of very high frequency/ultra high frequency (vhf/uhf) receiver radio frequency (rf) gain controls and to the authorized rf power output levels of vhf/uhf transmitters. Since operational situations that necessitate changes in these system parameters may develop after facility commissioning, the responsible AF field office implementing the change must coordinate with the concerned Air Traffic (AT) and Flight Standards (FS) field office and fully document the details of the changes. *

a. **Squelch Threshold and RF Gain Control Setting.** Ideally the rf gain control of all vhf and uhf receivers should be set for maximum usable gain, or slightly below the point where noise signals operate the squelch circuit. However, unfavorable noise or interference may exist at commissioning or may arise after commissioning that requires a reduced setting of the rf gain control for satisfactory receiver quieting. Operation at a reduced setting is authorized, provided that the reception range and coverage needed to meet operational requirements have been verified by aircraft reports and mathematical analysis, and that appropriate initial and operating tolerances are developed, approved, and published by the regional Airway Facilities division.

b. **Transmitter Power Output.** Ordinarily, transmitters used in PTP and a-g communication service shall be adjusted to emit authorized rf power output, except as required by Order 6610.3, Power Output Limitation: FSS, Terminal and Low Altitude Enroute VHF and UHF Transmitters. However, interference may arise that requires operation at reduced rf power output. Reduced power output may also be required for equipment related reasons. (See standards and tolerances for transmitter power output in chapter 3.) Operation with reduced power output is authorized, provided that the transmission range and coverage meet operational requirements as verified by aircraft reports and mathematical analysis, and that appropriate tolerances are developed, approved, and published by the regional Airway Facilities division.

5. CERTIFICATION REQUIREMENTS.

Refer to Order 6000.15A for general guidance on the certification of systems, subsystems, and equipment. Antennas and transmission lines are certified as an integral part of the communication facility with which they are associated.

6. PRECAUTIONS WHEN USING TEST TONES.

When making checks on any receiving channel, extreme care shall be taken to avoid applying test tones or other signals in excess of those prescribed by the procedures of this directive. Not only will an excessive test level cause crosstalk in adjacent telco or RCL channels, but it will also annoy operating personnel if the interfering signal is delivered to controller positions or is intercepted by maintenance personnel at other points in the system.

7. NONSTANDARD FACILITIES.

The instructions, descriptions, standards and tolerances, and procedures contained in this directive represent the agency's baseline, or standard criteria concerning PTP and a-g radio communication equipment. Some facilities under the purview of this directive may have been commissioned using equipment that was procured without benefit of agency-approved specifications. Regional procurement of equipment and devices to be used for air traffic control or navigation for which specifications have not received prior agency approval is prohibited by Order 1100.5B, FAA Organization - Field, paragraph 222j(2). The inclusion of such nonstandard equipments in this directive is for maintenance purposes only and as such will not be used as justification for procurement, installation, or commissioning of additional or similar equipment.

8. AUTHORIZED EMISSIONS.

The authorized emission types in the aeronautical mobile and fixed services are as follows.

a. **Telephony--Amplitude Modulation.**

(1) Double-sideband (used by FAA) A3

(2) Single-sideband, reduced carrier A3A

(3) Single-sideband, full carrier . . . . A3H (used by FAA)

(4) Single-sideband, suppressed carrier (used by FAA) A3J

(5) Two independent sidebands A3B

b. Telegraphy (Including Automatic Data Transmissions).

(1) Amplitude Modulation.

(a) Telegraphy without the use of a modulating audio frequency (by on-off keying) A1

(b) Telegraphy by the on-off keying of an amplitude-modulating audio frequency or audio frequencies, or by the on-keying of the modulated emission A2

(c) Multichannel voice-frequency telegraphy, single-sideband, reduced carrier A7A

(d) Multichannel voice-frequency telegraphy, single-sideband, full carrier A7J

(e) Multichannel voice-frequency telegraphy, single-sideband, suppressed carrier (used by FAA) A7J

(2) Frequency Modulation.

(a) Telegraphy by frequency-shift keying without the use of a modulating audio signal, one of two frequencies being emitted at any instant (used by FAA) F1

(b) Telegraphy by the on-off keying of a frequency-modulating audio frequency or by the on-off keying of a frequency-modulated emission F2

c. Facsimile. With modulation of the main carrier either directly or by a frequency-modulated subcarrier (used by FAA) A4

d. Aeronautical Mobile Service. Appendix 26 to the ITU Radio Regulations provides the frequency allotment plan and related information for the aeronautical mobile service. Included in the related information is a subsection, Classes of Emission and Power. Although intended for the aeronautical mobile service, the emission types listed as being permissible for the aeronautical mobile service are also the types that may be found in the aeronautical fixed service. The emission types used for hf a-g communications are generally restricted to A3, A3H, and A3J. Emission type A3H is also commonly referred to as ame, or am equivalent, because the full carrier operation provides for reception by conventional receivers, and the operation is therefore compatible with A3. In bi-mode a-g circuits, which are becoming widespread, the two modes are A3H and A3J with either emission type selectable by the operator as required by the operating procedures.

e. Aeronautical Fixed Service. The most commonly used emission types in the aeronautical fixed service are A3, A3A, A3B, A3H, A3J, and F1. The A1 emission remains in limited use in some parts of the world; it is being replaced by more modern types of emission as time and economical considerations permit. Independent-sideband (ISB) operation is used to provide one or more voice channels and/or more teletypewriter channels.

f. Reference. The Spectrum Management Regulations and Procedures Manual, Order 6050.32, provides information on frequency protection, radio coverage, and antenna lobing.

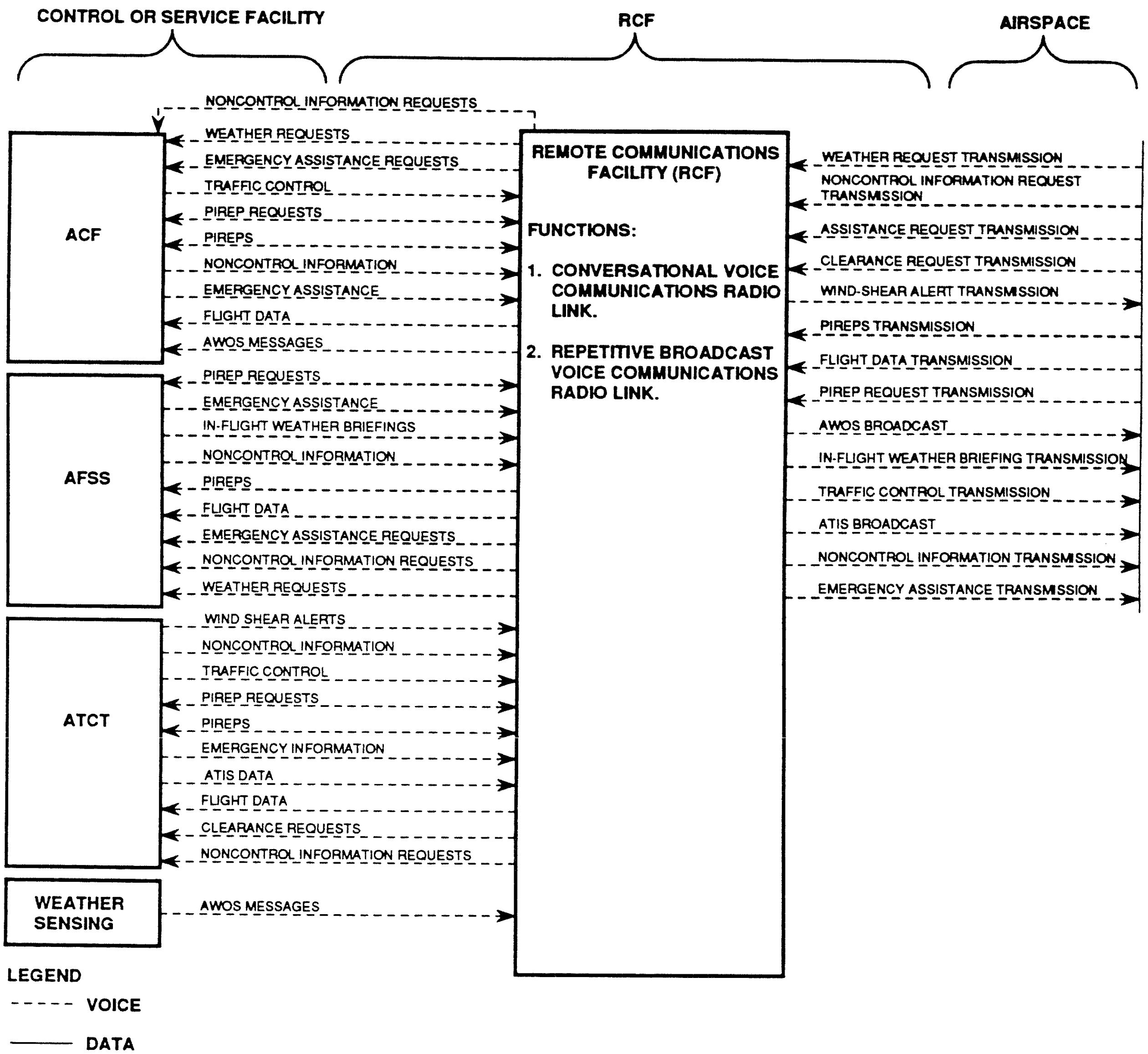
9.-19. RESERVED.

CHAPTER 2. TECHNICAL CHARACTERISTICS

20. PURPOSE OR FUNCTION.

The remote communication facility (RCF) consists of transmitters, receivers, transceivers, coaxial transmission lines, antennas, and associated ancillary equipment. It may be collocated with air traffic control or flight service facilities, with navigational aids (navaids) or radars, or it may be a stand-alone RCF installation. Figure 2-1, Basic Functions of the Remote Communication Facility, delineates many of the general functions of the RCF. The RCF communication system provides a medium for analog voice communications between air traffic controllers/specialists and both civil and military aircraft pilots operating under instrument flight rules (IFR) or visual flight rules (VFR) in domestic airspace. The system also provides recorded voice weather broadcasts to pilots over selected frequencies and antenna facility locations. The RCF system provides communication services to civil aircraft primarily via very high frequency (vhf) and to military aircraft via ultra high frequency (uhf). The RCF system encompasses en route, terminal, and flight service operations. A-g radio communication facilities originally were established according to regional requirements for each of the three air traffic functions, i.e., en route, terminal, and flight service operations. The facilities were formerly known as remote center air/ground communication facility (RCAG), remote communication outlet (RCO), and remote transmitters/receivers (RTR). Control facilities in each of the three operations are connected to the RCF. The location of the RCF is dependent upon the air space coverage assigned to particular frequencies and upon overall air space coverage assigned to the control facilities. The RCF a-g communication system is depicted in figure 2-2. It is characterized by a communication network, solid-state equipment, remote maintenance monitoring, and radio control equipment. The RCF and its tributary facilities are depicted in figure 2-3. Additionally, the equipment described in this chapter supports data, radio teletypewriter (rtty), and voice communication in the fixed and mobile aeronautical services. The official modes of operation used are listed in paragraph 8. Antennas and their coaxial feed lines provide an efficient means for the radiation and reception of radio frequency (rf) energy with a minimum loss of power.

21.-23. RESERVED.



FROM: NATIONAL AIRSPACE SYSTEM - LEVEL 1 DESIGN, NAS-00-10001

Figure 2-1. Basic Functions of the Remote Communication Facility

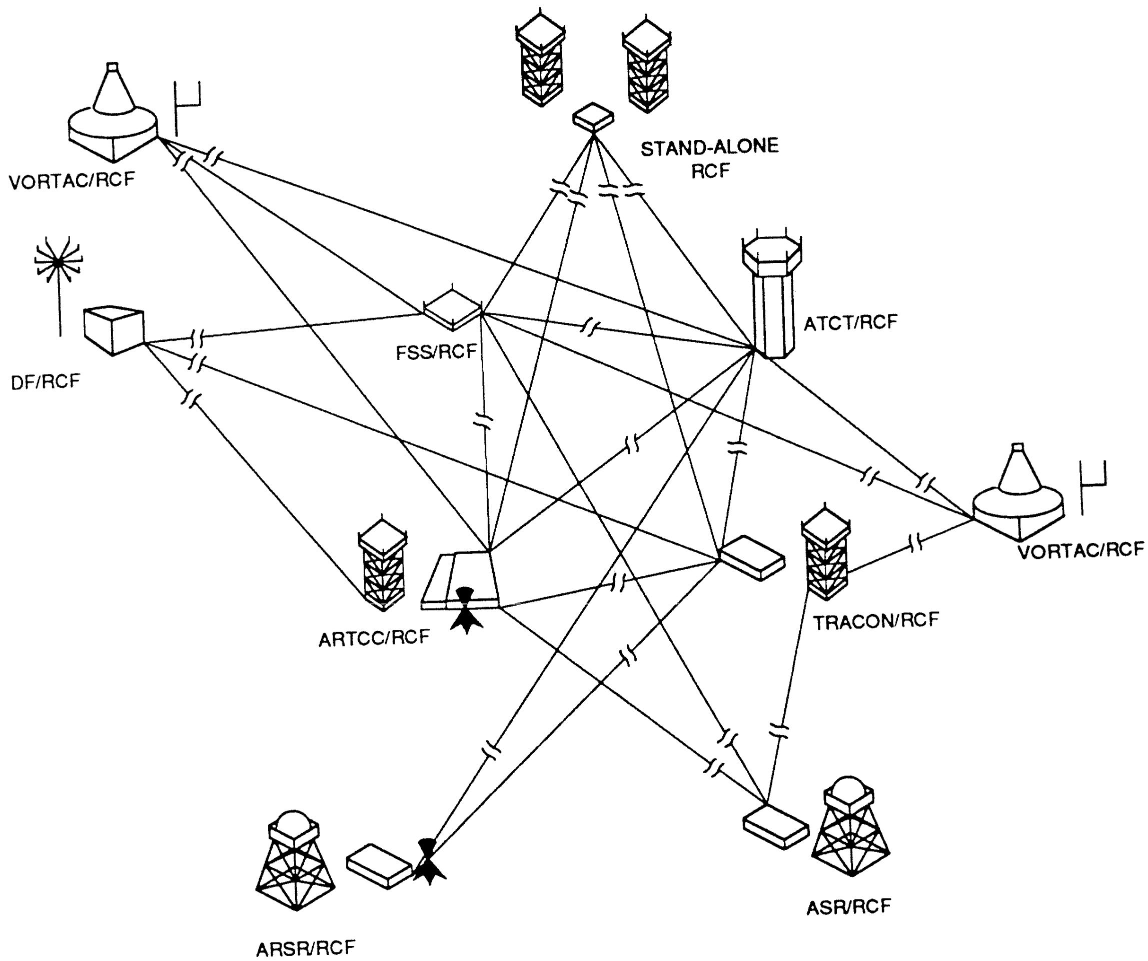


Figure 2-2. RCF A-G Radio Communication System

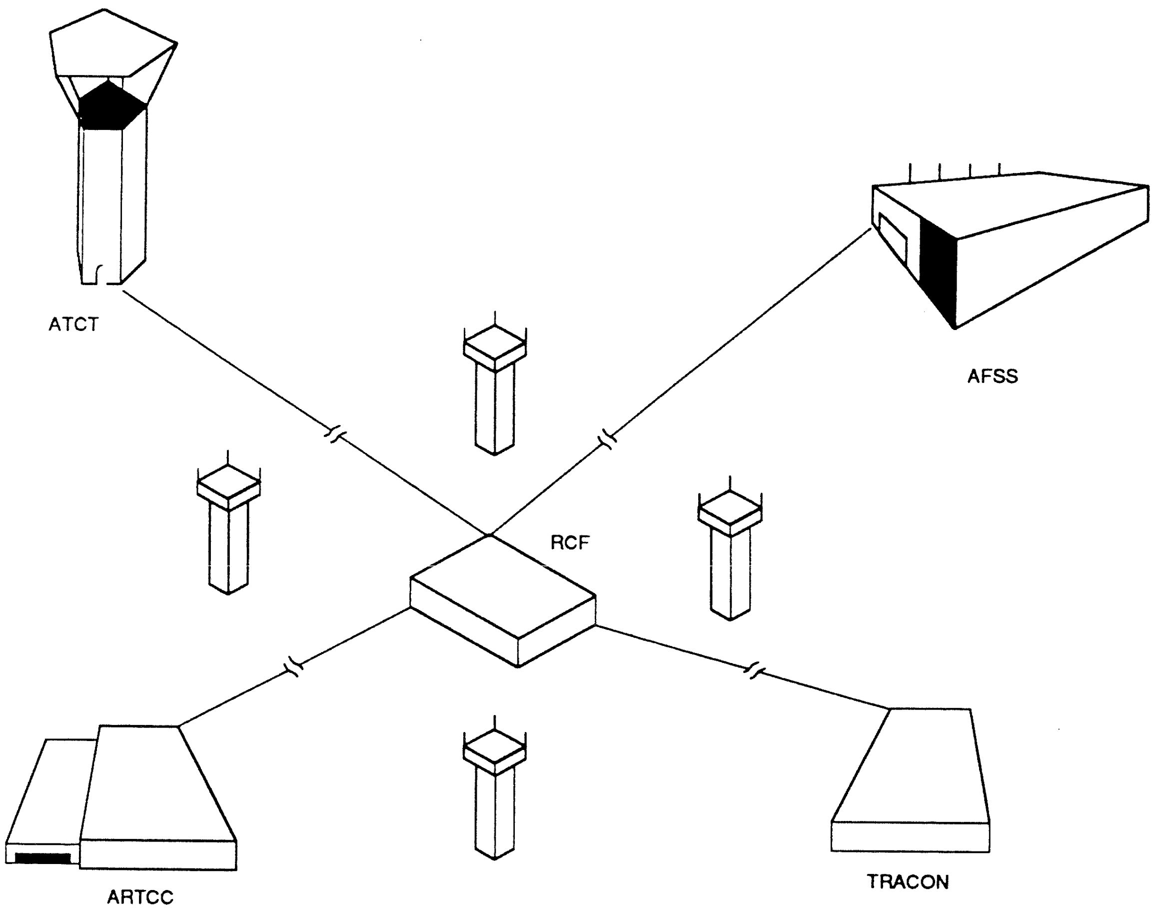


Figure 2-3. The RCF and Its Tributary Facilities

Section 1. RCF DESCRIPTION

Subsection 1. HIGH-FREQUENCY (HF) RCF

24. HF POINT-TO-POINT (PTP) AND AIR-TO-GROUND (A-G).

a. Ground-based PTP RCF's carry data and rtty traffic for the Aeronautical Fixed Telecommunications Network (AFTN) and the interregional administrative network. International flight service stations (IFSS) have message-switching capabilities for handling AFTN air movement and meteorological traffic from and to a large number of addresses. The hf a-g RCF handles two-way telephony between aircraft and ground stations. Radio transmitters and receivers operating as remote facilities of the IFSS, using hf equipment and antennas, are linked to the distant ground stations to which the switched traffic is addressed. The transmitters for PTP and a-g RCF's are the international flight service transmitters (IFST). The receiver facilities for the same a-g communication services are the internal flight service receivers (IFSR). The mode of transmission and reception used in these RCF's typically is single-sideband suppressed carrier (ssbsc) for data or rtty, or amplitude-modulated equivalent (ame) for the selective calling system (SELCAL). For analog voice broadcast which is ground-to-air (g-a) only communication, full-carrier amplitude modulation (am) is still used, pending full transition of airborne communication equipment from am to ssb. The VOLTMET (meteorological information for aircraft in flight) circuits that are used for en route or terminal weather advisory service are hf g-a circuits using the am mode. A typical IFSS communication hf PTP and a-g network is depicted in figure 2-4 with the various antennas used for different services. The figure intentionally does not show all commissioned circuits. Some circuits back up subsea cable channels leased by FAA. Note that uhf links are used to carry data, voice, or rtty handled by the transmitters and receivers between the IFSS and IFSR. A typical antenna farm for an IFSR RCF is depicted in figure 2-5.

b. The data or rtty ssb transmitters and receivers are interconnected with frequency-division multiplex (fdm) terminals so that up to 24 channels of data may be accommodated in the 3kHz voice band that occupies the upper sideband (usb) of the ssb radiated signal. The lower sideband (lsb) has been filtered out in the transmitters. Some ssb circuits use independent sideband (isb) with suppressed carrier, where both usb and lsb 3kHz voice-frequency bands can be operating independently of each other over the same circuit. In system planning, the choice of ssb over am is based on spectrum economy. It is possible to carry the same amount of traffic in the ssb mode in approximately half the frequency spectrum needed for the am mode. Also, in the am mode, half the transmission power is "wasted" in the carrier required to enable demodulation by the am receiver.

c. Maintaining communication over an hf PTP RCF or a-g RCF usually requires the assignment of more than one frequency in the space between 3MHz and 30MHz. The family of frequencies allocated is carefully chosen at the time the circuit is engineered, taking into consideration such factors as distance, east-west or north-south orientation of the path, hours and days of operation, antenna gains and transmitter powers, propagation, noise, and multiplexing requirements. Predictions based on reliability expectations for frequencies or frequency bands are published by the National Bureau of Standards (NBS) and are used by IFST, IFSR, and operations personnel to maintain around-the-clock communication continuity. This is done by scheduling and correlating frequency changes based on NBS predictions for the path.

25. HF VOICE BROADCAST.

One-way broadcast telephony is used to advise aircraft in flight of en route and terminal weather conditions and airport runway and traffic conditions. VOLMET is international g-a hf voice broadcast service providing meteorological data to in-flight aircraft. Vhf and uhf channels are also used for broadcast; however, hf propagation is used for long distance advisory services, usually to assist aircraft in transoceanic flight.

26.-29. RESERVED.

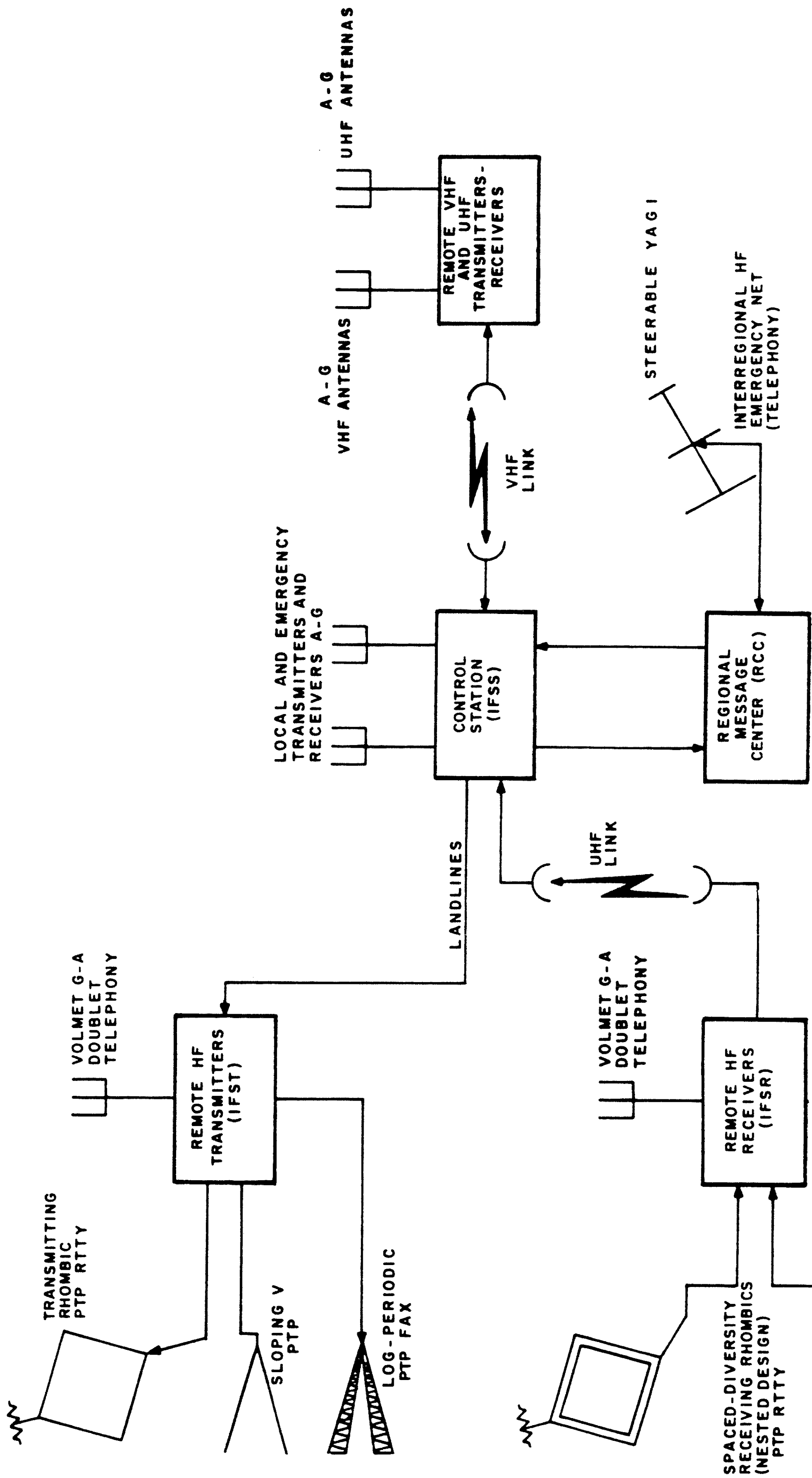


Figure 2-4. Typical IFSS Communication HF PTP A-G Network

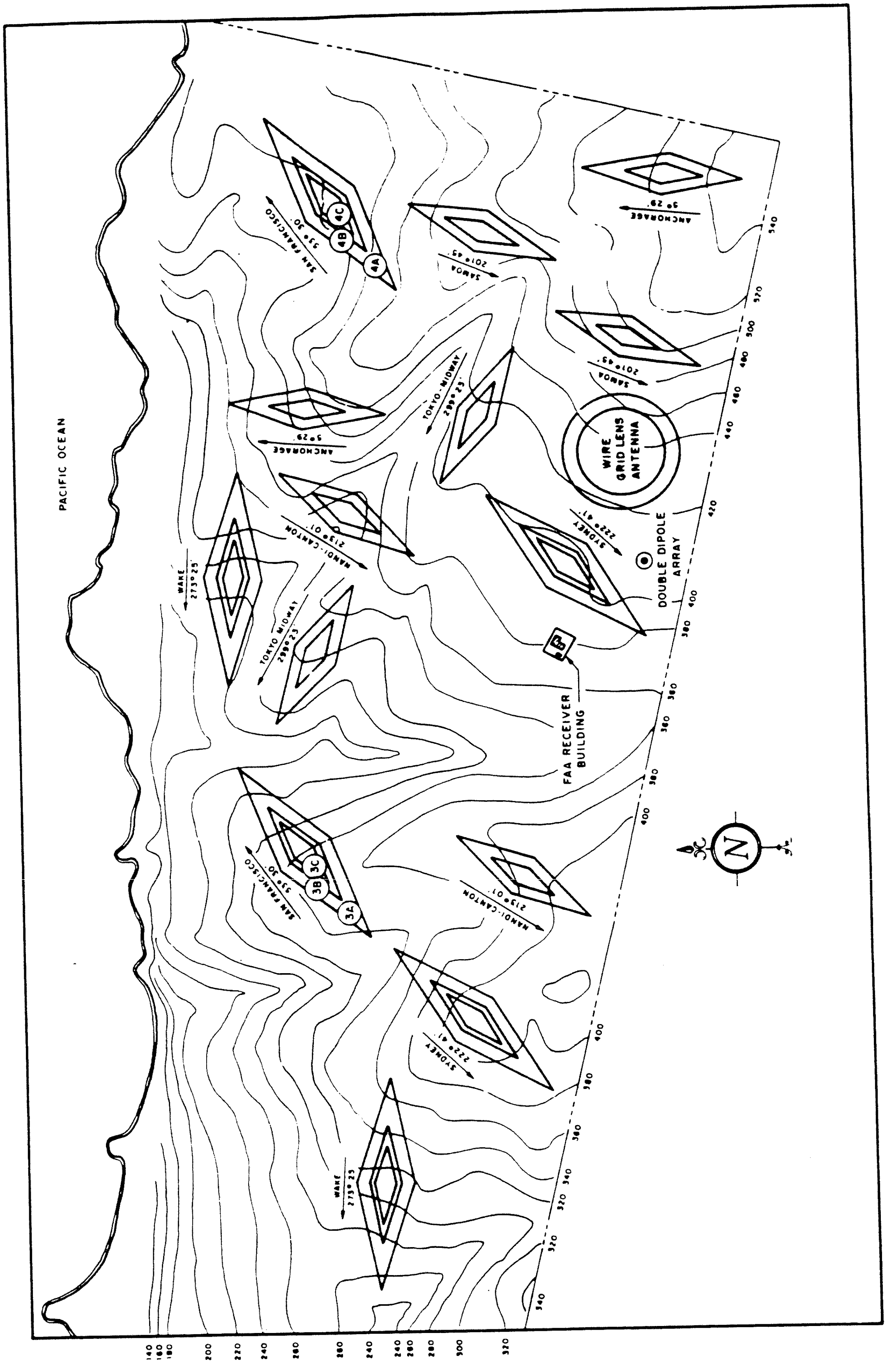


Figure 2-5. Typical Antenna Farm for an IFSR RCF

Subsection 2. VHF AND UHF RCF

30. AIR TRAFFIC CONTROL/SERVICE.

Ground-based uhf and vhf transmitting and receiving RCF's engage in two-way telephony with aircraft both on the ground and in flight. Terminal service for commercial aircraft includes clearance delivery, ground control, local control, departure control, and other functions, some of which are exclusively handled by airlines. En route control is of either low altitude or high altitude two-way communication from air route traffic control centers (ARTCC) via RCF's. Vhf radio frequencies are normally used for communication with commercial aircraft, while uhf frequencies are used with military aircraft. Figure 2-6 illustrates a typical a-g radio communication system. Typical transmitters in these facilities operate with 10 or 50 watts for vhf, and 10, 50, or 90 watts for uhf. Powers are determined by the operational range required and certain noninterference criteria. For power output policy, refer to Order 6610.3, Power Output Limitation: Flight Service Station, Terminal, and Low Altitude En Route VHF and UHF Transmitters. System description and maintenance requirements for en route, terminal, and flight service station communications facilities are covered by the Order 6470.29A, Maintenance of En Route Air-to-Ground Communications Facilities, Order 6480.6B, Maintenance of Terminal Air-to-Ground (A-G) communications Facilities, and Order 6490.1A, Maintenance of Flight Service Station (FSS) Air-to-Ground Communication Facilities.

31. EXTENDED REMOTE CENTER AIR-TO-GROUND (ERACG) COMMUNICATION FACILITIES.

The ERACG transmitter and receiver site provides vhf communication between the center and air craft at extended distances from land. The original concept of ERCAG facilities was to provide high-power, land-based equipment to communicate with the standard complement of commercial vhf radio equipment. A later refinement of the facility design was to use the standard AN/GRT-21 and AN/GRR-23, 50-watt equipment with an antenna mounted on a 200-foot to 300-foot tower. This provided similar a-g radio communication capability because of the limited transmitting range of the low-power aircraft transmitters.

* **32. REMOTE TRANSMITTER/RECEIVER CLASS O (RTR-O) AND REMOTE COMMUNICATIONS OUTLET CLASS O (RCO-O) COMMUNICATION FACILITIES.**

a. The RTR-O and RCO-O facility designations were established to eliminate the older single-frequency outlet (SFO) designation. This change was necessary to avoid overlapping definitions in the standard codes handbook, Air Traffic documents, and the Facilities Master File (FMF). An RTR-O is controlled by a terminal facility such as an ATCT, and an RCO-O is controlled by an FSS or AFSS.

b. These facilities provide ground-to-ground communications between air traffic control and pilots located at satellite airports. This communication link is for delivering en route clearances, issuing departure authorizations, and acknowledging instrument flight rules cancellations or departure/landing times. In addition, the facility may be utilized for advisory purposes whenever the aircraft is below the coverage of the primary air-to-ground frequencies.

c. The RTR-O or RCO-O facility consists of an equipment shelter, that houses a single transmitter and receiver, and an antenna. The equipment shelter may be pole mounted or attached to an interior/exterior wall of a building, with the antenna being roof or pole mounted. In addition, the radio gear may be removed from the shelter and mounted in a rack within a building when such location is available. A voice grade line with in-band signaling provides the point-to-point voice and push-to-talk control features. Voice-frequency signaling equipment may also be utilized for control of the facility. Commercial power is used for powering the radio and/or signaling gear and the telephone company equipment. Standby power and alternate telephone circuits are not required. *

33.-35. RESERVED.

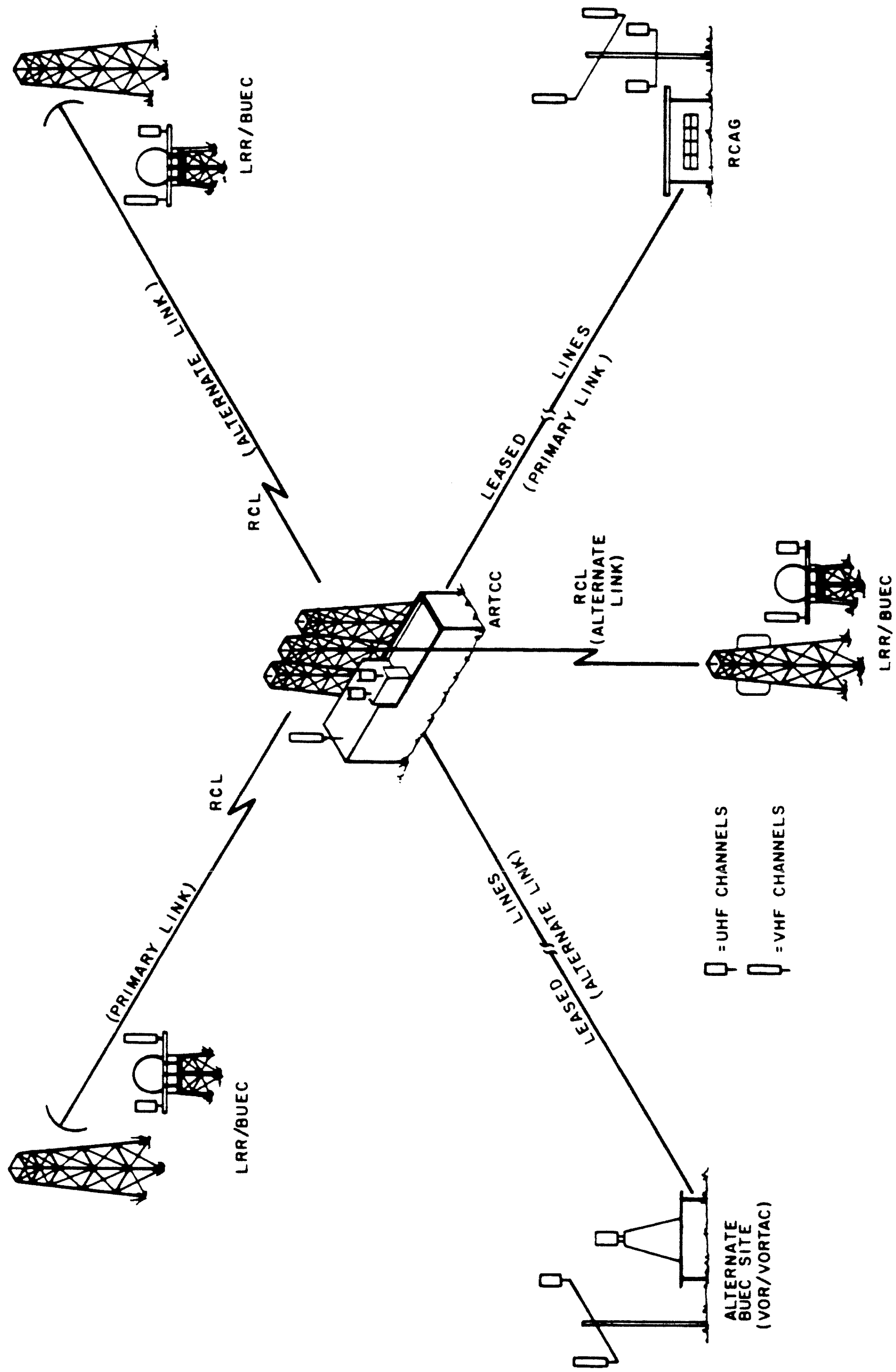


Figure 2-6. A-G Radio Communication System

Section 2. HF EQUIPMENT DESCRIPTION

36. GENERAL.

This section contains brief descriptions of typical hf transmitters, receivers, transceivers, coaxial transmission lines, antennas, associated ancillary equipment, and wave propagation. For a fuller description and all equipment theory, consult the applicable equipment instruction books and manuals.

37. MODES OF OPERATION.

The A3 am function is referred to as the am mode; the A3A, A3H, and A3J ssb functions are referred to as the ssb mode. See paragraph 8 for the modes of operation authorized for aeronautical and fixed service.

38.-39. RESERVED.

Subsection 1. RF EQUIPMENT

40. HF TRANSMITTERS.

a. Aerocom Model 1330 5kW Transmitter. Figure 2-7 is a block diagram of a typical ssb hf transmitter, capable of high-power multimode operation with full, reduced, or suppressed carrier. In the figure, the principal low-power stages are the sideband exciter and the frequency converter. An intermediate radio frequency (rf) amplifier provides amplification of one of six assigned frequencies. Further amplification occurs in the final linear amplifier where peak envelope powers (PEP) up to 5000 watts are developed. The audio input, which may be voice or frequency-division-multiplexed (fdm) tones, first goes to a balanced mixer where the 1.75MHz carrier is inserted. The carrier and two audio sidebands go to a sideband filter that removes the upper sideband from the carrier allowing the lower sideband to be fed through another mixer and finally to a third mixer in an up and down conversion arrangement designed to minimize frequency instability. The lower sideband is inverted to become the upper sideband and is amplified to a high rf output level. The usual method of generating an ssb signal is the balanced modulator-filter arrangement of figure 2-8. Figure 2-9 illustrates various undistorted ssb modulation waveforms for different audio input signals. Part E of the figure is the typical two-tone, suppressed carrier modulation waveform. Part F is the extreme case of modulation with a square-wave signal, which results in infinitely-high excursions at the beginning and end of each pulse and places great demands on the transmitting system.

b. Aerocom Model 1311 1kW Transmitter. This transmitter is similar to the model 1330, except that a type 131-1, 1kW linear amplifier is the final amplifier element. The exciter and converter-driver elements are the same as those used with the model 1330 5kW transmitter.

c. Aerocom SSB Generator Type 125-1. The ssb generator is the basic exciter unit of the model 1330 and 1311 transmitters. It drives a converter-driver stage with a lower sideband (lsb) signal at 1.75MHz. Its audio input comes from either a local dynamic microphone or a 500-ohm or 600-ohm impedance telephone line. It has 20dB of compression and a harmonic distortion limit of 3 percent. The crystal filter limits the passband of the lsb to 300Hz to 3000Hz. A balanced modulator is the basic exciter element, and the carrier may be removed or reinserted depending on the desired operational mode. Refer to figure 2-8 for a diagram showing lsb generation.

d. Aerocom Converter-Driver Type 127-1. The converter-driver is a six-channel intermediate amplifier. It converts the 1.75MHz ssb signal from sideband generator type 125-1 to the desired channel operating frequency at sufficient rf power to drive either a 1kW PEP or 5kW PEP linear amplifier. The rf drive voltage to the following linear amplifier stage is nominally 10V across a 50-ohm load, or 2W. A crystal oscillator, called the vhf oscillator, feeds the final mixer of the converter driver to produce the channel frequency. An oven-controlled hf crystal oscillator provides carrier frequency 1.75MHz and mixes this frequency with the signal from the exciter. Channel frequency stability is governed by the hf oscillator and the accuracy of the 1.75MHz ssb input signal.

e. Miscellaneous Fixed-Tune Transmitters.

(1) Technical Material Corporation Model GPT-10kW Transmitters. The GPT-10K transmitter is an older but serviceable unit that is capable of 10kW PEP operation on all authorized modes of operation. It may be used on am, ssb, and continuous-wave (cw) circuits handling facsimile, rtty, or broadcast traffic. The 1kW intermediate power amplifier (ipa) may be used as a transmitter if the final power amplifier (pa) fails or if the radiated power need not be a full 10kW. The transmitter is bandswitched for frequency changing from 2MHz to 28MHz. The final amplifier will drive an unbalanced or a balanced antenna feeder; the former can be 50-ohm or 70-ohm, and the latter, 600-ohm impedance.

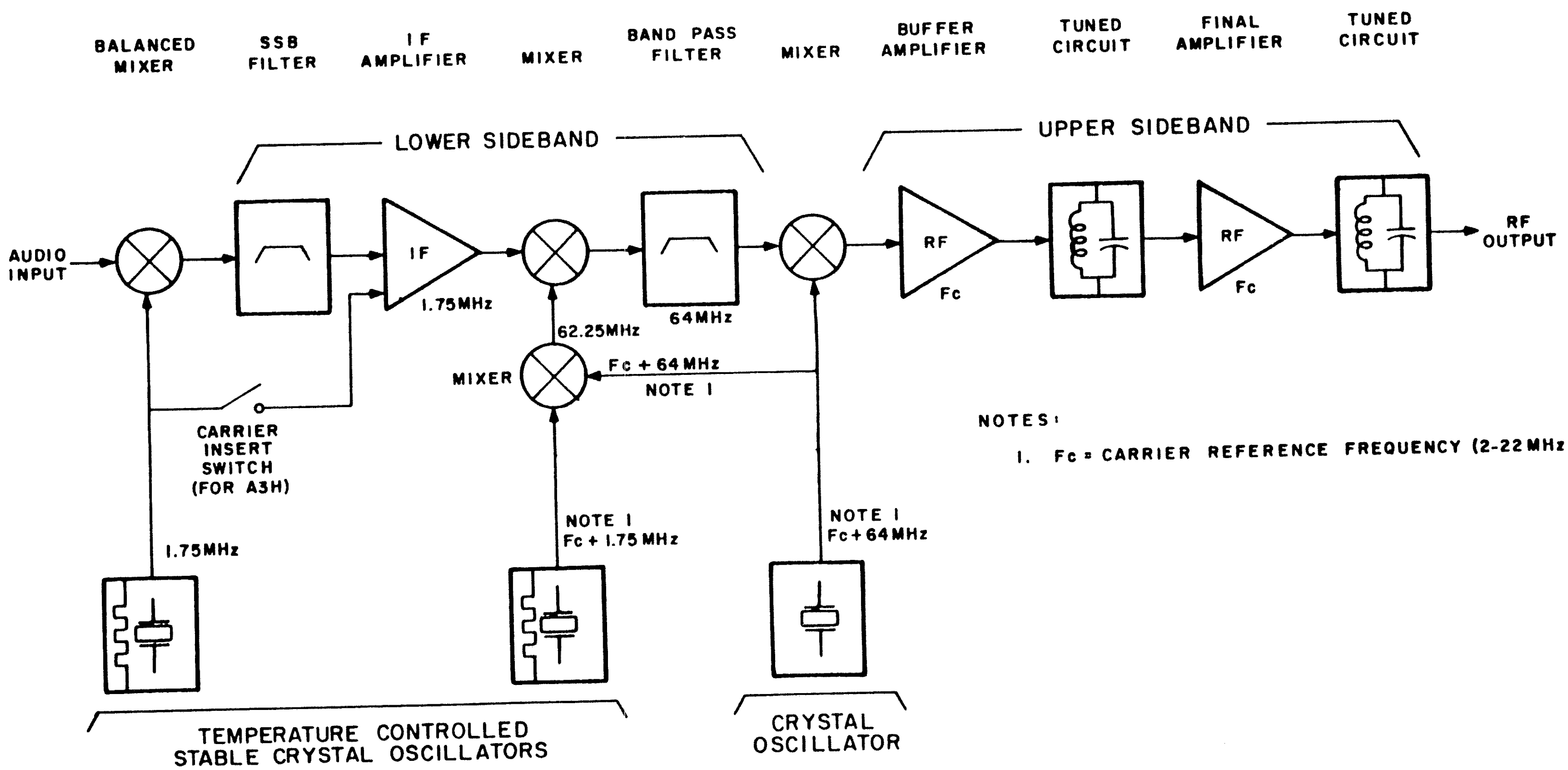


Figure 2-7. Block Diagram of an HF SSB Transmitter

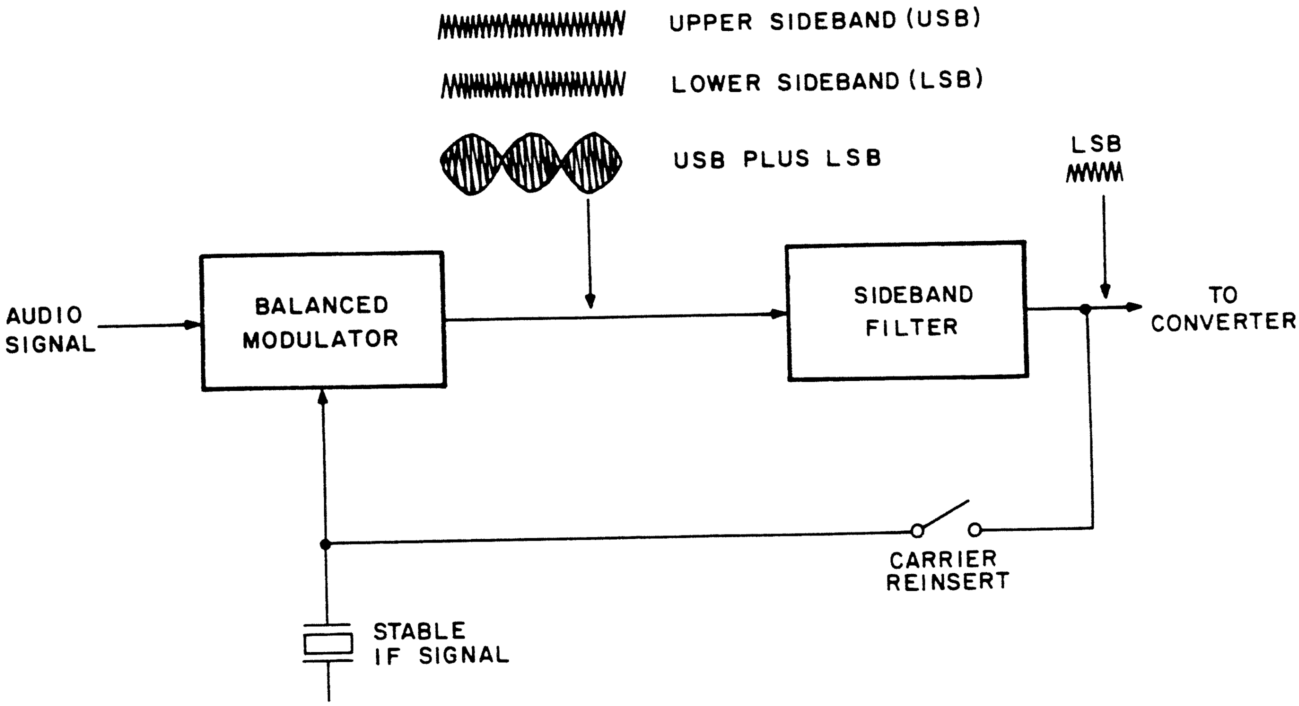


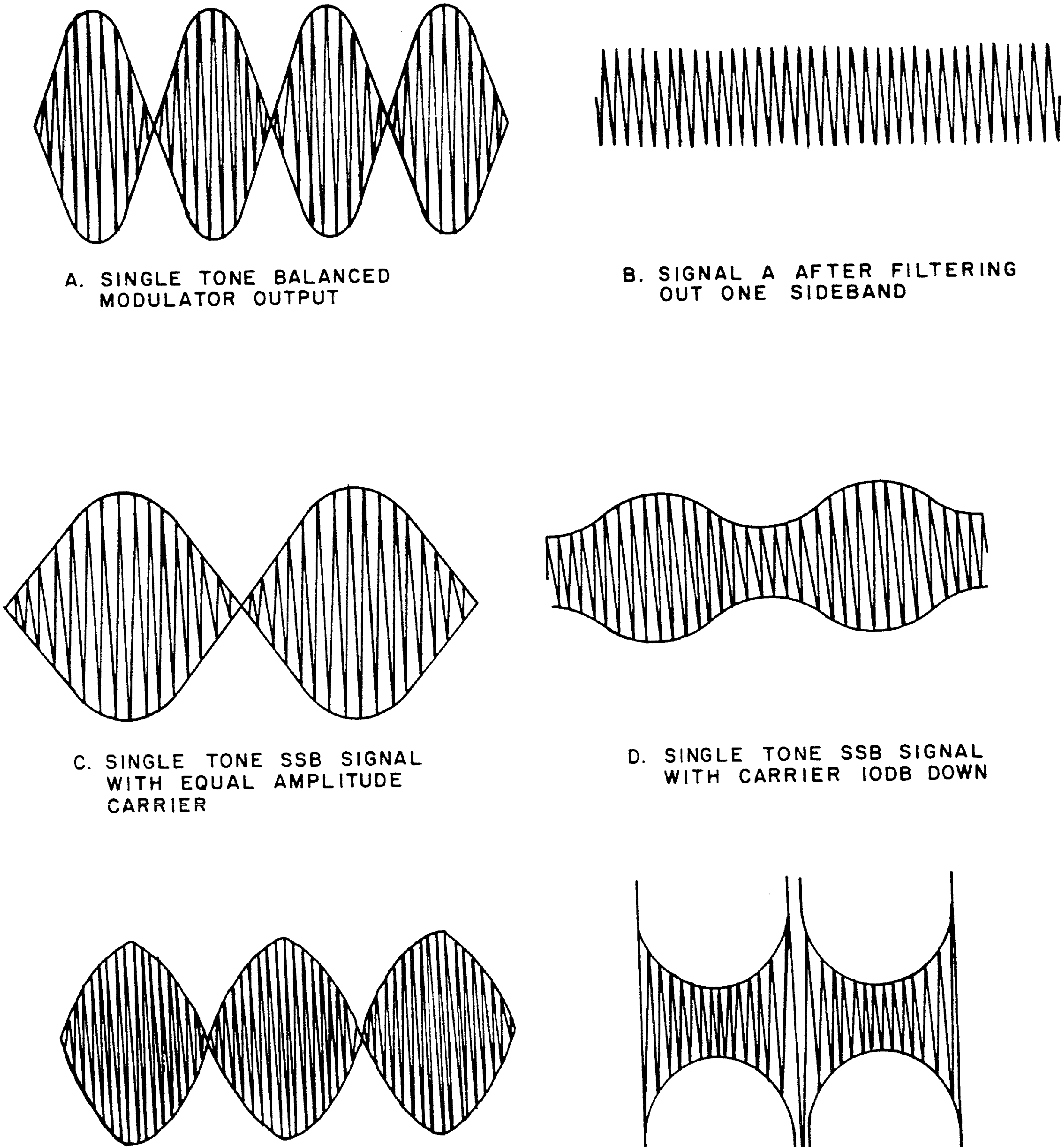
Figure 2-8. Single Sideband Generation

(2) **Collins Radio Company Model 205J 10kW Transmitter.** The Collins 205J has been used on FAA long-haul PTP rtty circuits. It is bandswitched over a range similar to that of the GPT-10K. It will accommodate all authorized operating modes for data communication, voice broadcast, or facsimile. It may be used with either an unbalanced (50-ohm) or balanced (600-ohm) antenna feeder.

(3) **THV-1 and THV-2 3kW Transmitters.** The THV series provides a cw, rtty, and am 3kW multichannel transmitter. Frequencies are pretuned in up to five identical rf bays from 2MHz to 20MHz. The associated power supply is in a larger, separate bay. An audio modulator bay can be added for broadcast application by dropping one rf bay.

41. HF RECEIVERS.

a. **Aerocom Model 2210 SSB-AM Receiver.** Figure 2-10 is a block diagram of a typical hf ssb ground station receiver capable of multimode operations: ssb, am, and ame (am equivalent). The frequency range is nominally 2MHz to 22MHz. The receiver is intended primarily for a-g and broadcast communication. For a more detailed block diagram of the same receiver, refer to the instruction manual for the Aerocom 2210 hf am/ssb receiver. As shown in the figure, the incoming rf signal is converted to 64MHz in the first mixer. The 64MHz intermediate frequency (if) is the first if frequency. A crystal bandpass filter centered at 64MHz removes spurious mixer products. After the filter, the second mixer converts the 64MHz if to 1.75MHz, which is the second if frequency. The double-conversion process provides good rf selectivity without a preselector stage. Crystal lattice filters provide both am/ame and ssb mode selectivity at the second if frequency. The detector is a phased-locked loop common to both am and ssb modes. The second if signal is injected with a highly stable 1.75MHz oscillator signal for carrier reinsertion for ssb demodulation. A fast attack, slow decay automatic gain control (agc) circuit allows smooth reception at a speech-syllabic rate. Solid-state components are used throughout. The rf input circuit is a double-balanced Schottky diode mixer having excellent low intermodulation characteristics. The second if crystal lattice filters are of eight-pole configuration. The output audio amplifier connects to either speech or rtty multiplex (mux) demodulator equipment.



A. SINGLE TONE BALANCED MODULATOR OUTPUT

B. SIGNAL A AFTER FILTERING OUT ONE SIDEBAND

C. SINGLE TONE SSB SIGNAL WITH EQUAL AMPLITUDE CARRIER

D. SINGLE TONE SSB SIGNAL WITH CARRIER 10DB DOWN

E. TWO EQUAL AMPLITUDE TONES, SUPPRESSED CARRIER SSB

F. SSB SIGNAL WITH SQUARE-WAVE MODULATION

Figure 2-9. Single Sideband Modulation Patterns

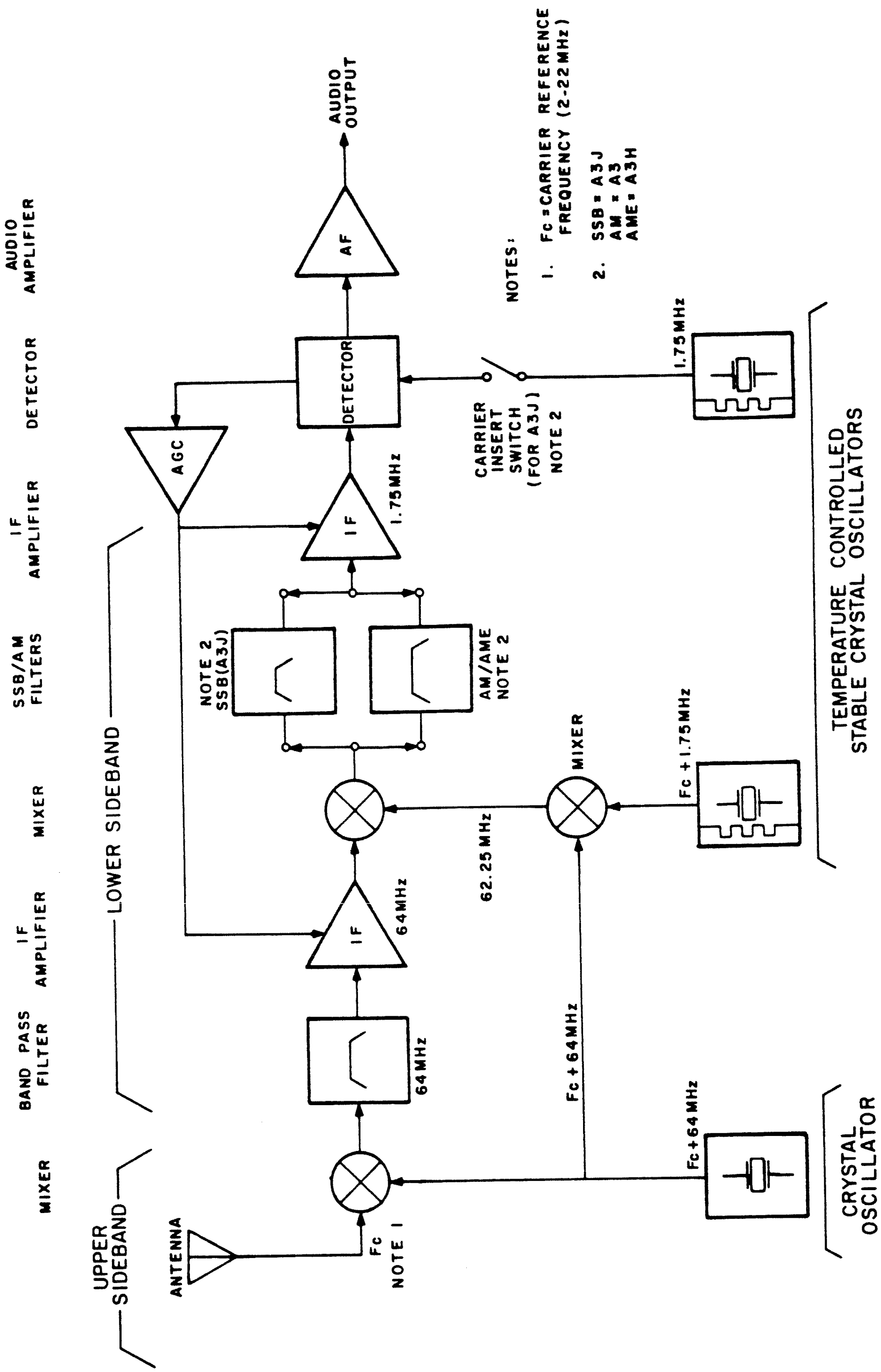


Figure 2-10. Block Diagram of a High-Frequency SSB Receiver

b. Miscellaneous Fixed-Tuned Receivers. A number of other ssb and am receivers have been used in PTP hf service. Prominent among these is the Radio Corporation of America (RCA) model SSB-R3 dual-diversity receiving system. The type SSB-R3 covers 2.8MHz to 28MHz in four bands. The receiver system is contained in two relay racks. Its frequency-shift tone output will accommodate 20 fdm channels in one sideband from 595Hz to 3825Hz. It is designed to operate from two space-diversity receiving antennas; for example, a pair of rhombic antennas oriented to the same azimuth but spaced up to several thousand feet (meters) from each other to combat the effects of fading. The receiver will handle facsimile reception as well as voice. The most common FAA use has been on 100-words-per-minute (wpm) rtty circuits in the aeronautical fixed service.

42.-43. RESERVED.

Subsection 2. TRANSMISSION LINES

44. GENERAL.

Several types of transmissioin lines are used in communications. Some of these are illustrated in figure 2-11. The two-wire, or open-wire, type is widely used for frequencies below 30MHz. This type consists of two wires mounted equal distances above the earth with constant spacing between the wires.

45.RESERVED.

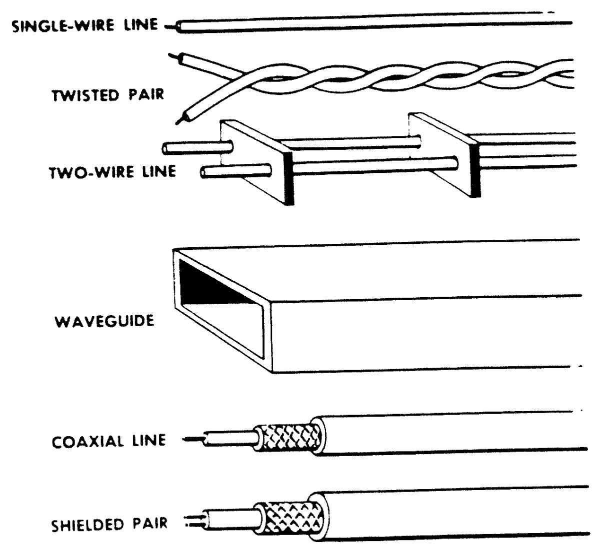


Figure 2-11. Typical Forms of Transmission Lines

Subsection 3. ANTENNAS

46. GENERAL

Below 30MHz, antennas are usually large structures occupying a relatively large amount of land. As transmitting antennas, they must be capable of handling large amounts of rf power, be directive, and have relatively high forward gain. With such antennas, it is important that their front-to-back signal discrimination be large to minimize atmospheric and man-made noise and to suppress interfering signals. Fixed point-to-point (PTP) antennas are oriented to place their maximum radiation on a precise great-circle azimuth. High-frequency (hf) broadcast (ground-to-air) antennas are omnidirectional. Loop and lens-type antennas with selectable directivity provide moderate gain on air-to-ground (a-g) and ship-to-shore (STS) circuits. Figures 2-12 through 2-15 show various types of antennas, operating in various government bands from 3MHz to 30MHz.

47. HF POINT-TO-POINT AND BROADCAST ANTENNAS.

a. Antennas used for fixed station, point-to-point transmission are large and have a broadband characteristic. They are highly directive with large front-to-back gain ratios to minimize interference, and high forward gain with respect to an isotropic antenna to overcome the large transmission loss of the hf circuit. The antenna of greatest importance in hf communication for many years has been the rhombic antenna. This antenna operates on a fixed azimuth, may have a multiwire curtain in its legs for obtaining a broadband characteristic and lower impedance, is usually many wavelengths in length on each leg, and, consequently, requires a large plot of ground for installation. Figure 2-16 is a simplified drawing of a rhombic antenna equipped with a dissipation line as terminating impedance. The dissipation line provides the antenna with uniazimuth directivity; otherwise, it would radiate at the feed end as well as at the terminated end. The characteristic impedance of the rhombic antenna at its balanced feed point is approximately 600 to 800 ohms. When unbalanced feed is required, a balance-to-unbalance transformer (balun) is connected to the input of the antenna with its high-impedance terminals. The low-impedance, unbalanced side of the balun is connected to coaxial transmission line for further connection to the associated transmitter or receiver. The directivity of the rhombic antenna is depicted by figure 2-17, which illustrates the horizontal and vertic plane patterns of the antenna. In forming the resultant radiation pattern, each leg of the rhombic antenna acts like one or more long-wire antennas. The terminating resistor (a dissipation line for high-power transmitters) permits the radiation that would normally be emitted to the rear of the antenna to be dissipated in the terminating resistance. This produces an essentially unidirectional pattern with one major forward lobe for orientation on the great-circle azimuth. There are a number of minor lobes, but no radiation 180° (back-azimuth) from the major forward lobe. The vertical radiation angle depends primarily on the length of each leg: the longer the leg, the lower the radiation angle (figure 2-17). Consequently, the antenna can be used over greater distances with fewer hops and less total refraction loss.

b. Related to the rhombic antenna, the V antenna (sometimes erected as a sloping V) has the open end pointed in the desired direction of radiation. The apex terminal of the V is balanced and connected via open wire (or, with a balun, via coaxial cable) to the transmitter or receiver. The V antenna lacks the sharp directivity and high gain of the rhombic antenna. In its sloping V form it provides a very low radiation angle, a characteristic of value for long-distance paths. Figure 2-18 shows a terminated sloping V antenna.

c. Doublet antennas are used on hf circuits having short-haul groundwave or one-hop communication requirements. They have moderate directivity and unity gain (relative to a dipole) and can be operated only over a relatively restricted range of frequencies. They exhibit broadband characteristics only when multiplied in double-doublet or triple-doublet arrangements. They can be fed with a low impedance (approximately 70 to 100 ohms) twisted or open transmission line. For unbalanced coaxial line feed, a balun is required. The Granger Associates Model 1765-22 broadband dipole antenna is a multiwire doublet as shown in figure 2-19. It can be used for either transmitting or receiving and has a frequency range of 3.4MHz to 30MHz. Its swr is a nominal 2:1 in that range. The length of the antenna between mounting poles is 185 feet (56.4 meters). The height is 68 feet (20.7 meters), and the width is 134 feet (40.8 meters). The radiation pattern is omnidirectional at the lower frequencies. In transmitting usage, its power-handling capability is 1 to 2 kW.

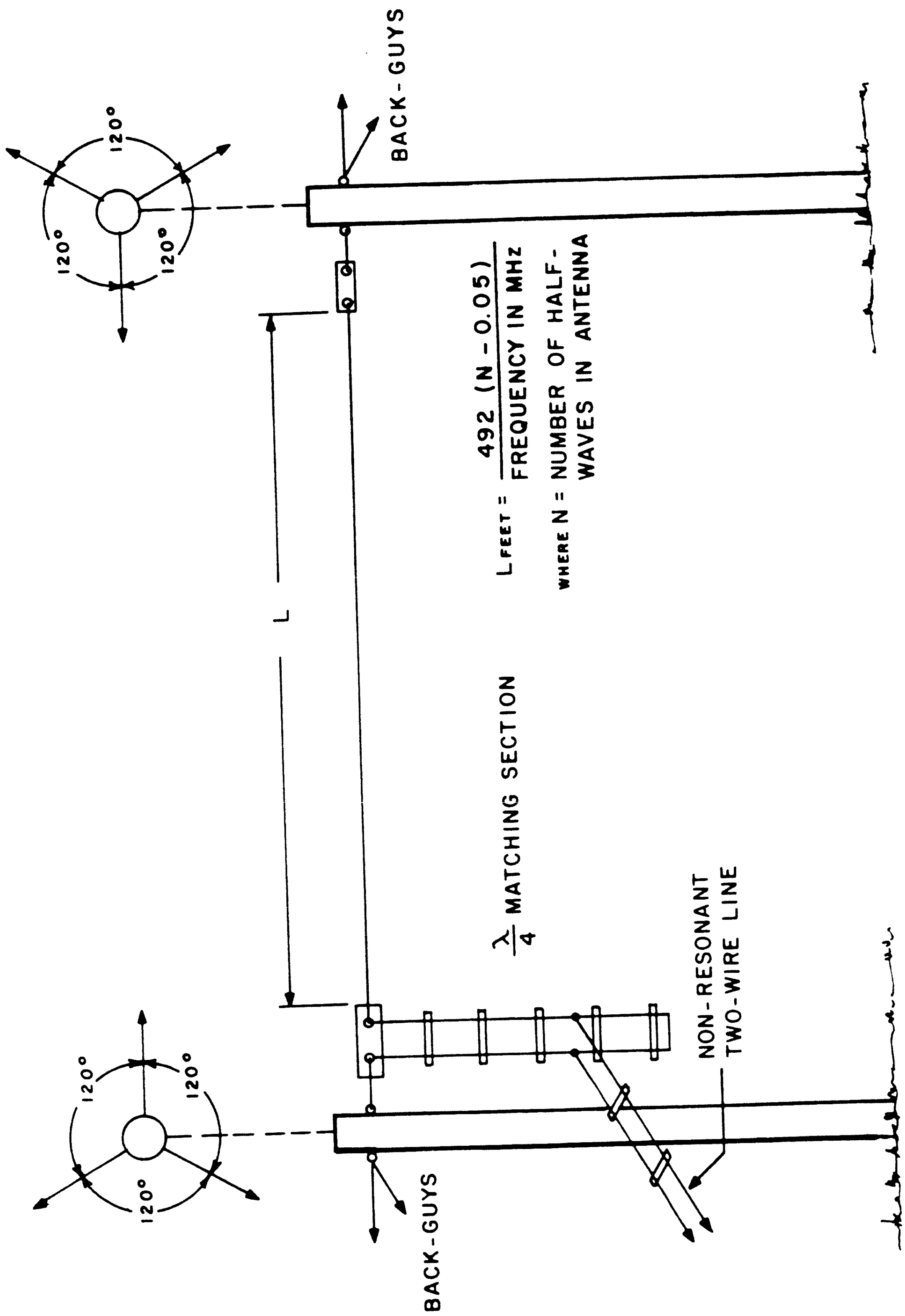


Figure 2-12. Long-Wire Antenna

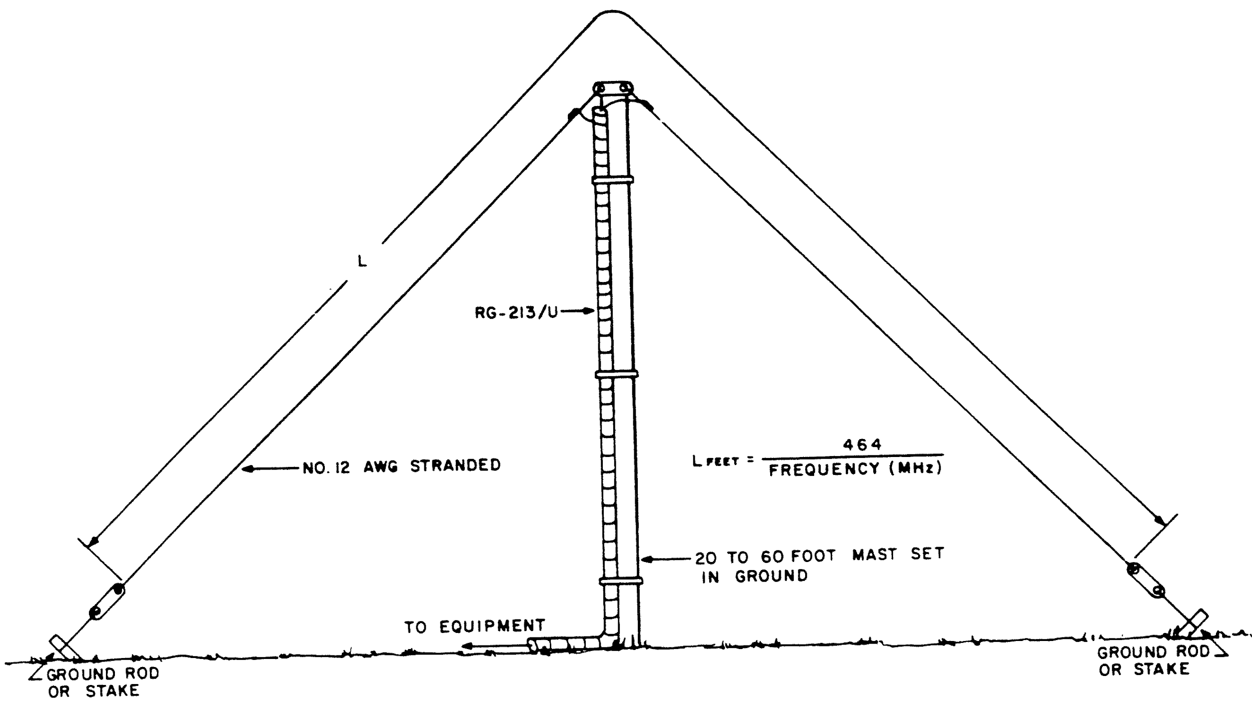


Figure 2-13. Vertical V Antenna

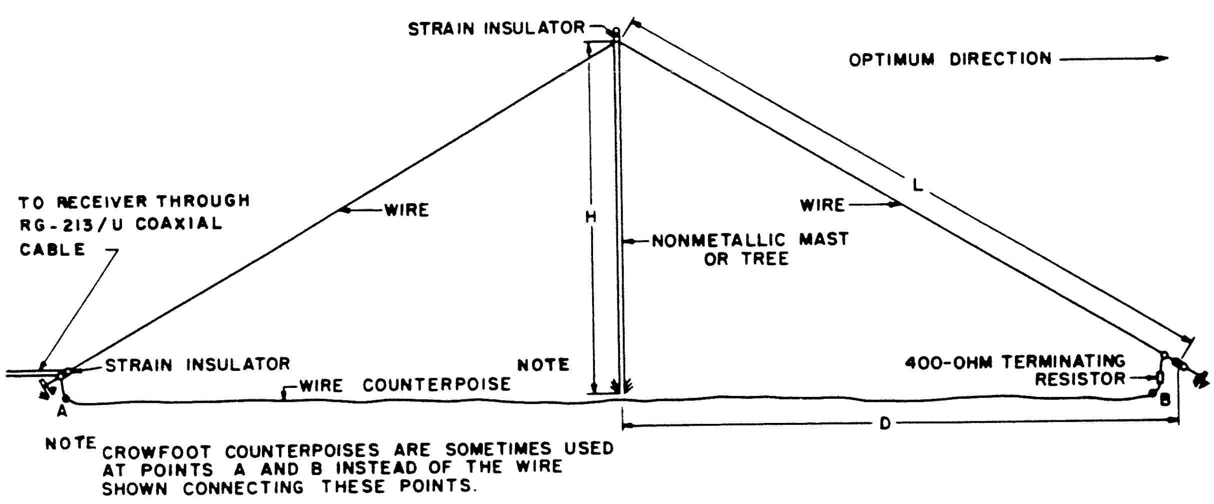


Figure 2-14. Vertical Half-Rhombic Antenna

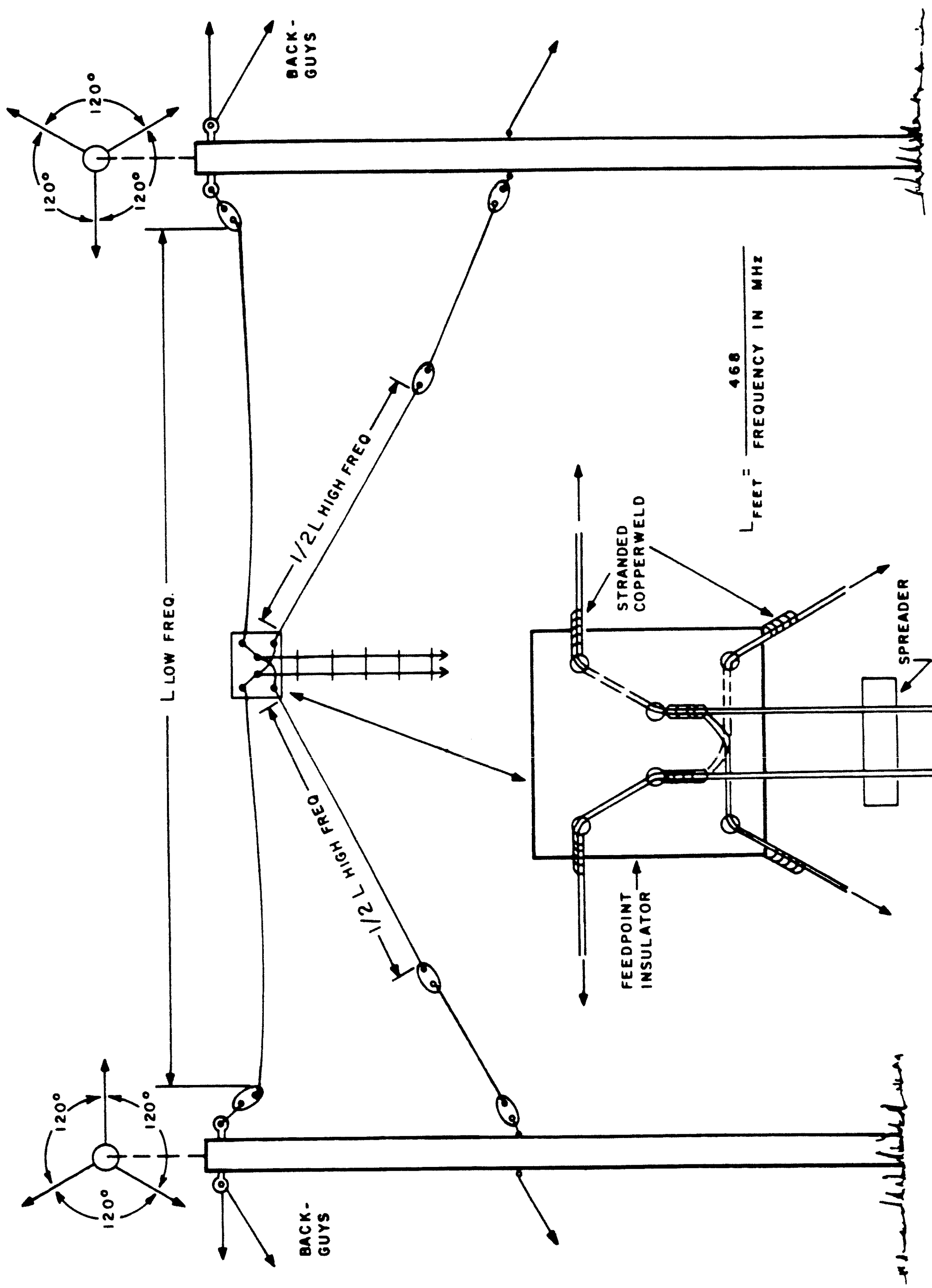


Figure 2-15. Multiwire Doublet Antenna

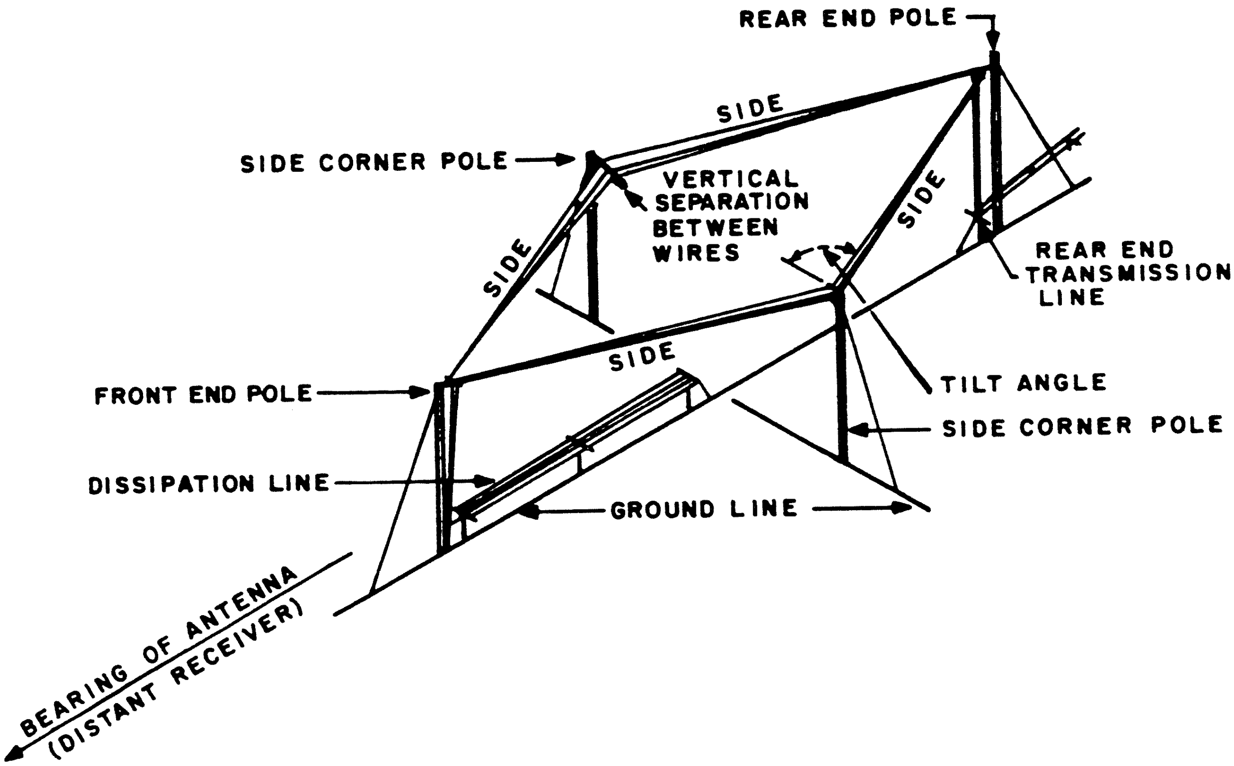


Figure 2-16. Transmitting Rhombic Antenna with Three-Wire Curtain and Dissipation Line

d. The Tanner wire-grid lens antenna is a highly specialized broadband multiazimuth antenna located at the Molokai, Hawaii, FAA receiving station. Originally erected with seven feed points, the Molokai wire-grid lens has been used not only on FAA radio teletypewriter (rtty) circuits to Australia, American Samoa, New Zealand, Japan, Canton Island, Wake, and Guam, but also for ship-to-shore communication for the Pacific Missile Range. The wire-grid lens has the unique ability to permit rapid azimuth changes, during circuit requirement changes, by relocating the coupling horns around the outer circumference of the grid. The lens can readily substitute for a number of rhombic antennas on different azimuths, resulting in a great saving in land requirements for the antenna farm. The antenna is illustrated in figure 2-20. The wire-grid lens consists of a pair of circular grids, 600 feet (182.9m) in diameter, suspended one above the other. Surrounding the lens proper is the horn, which increases the diameter of the array to 850 feet (259.1m). The horn is analogous to the old-fashioned ear trumpet. It intercepts the wave-front power, concentrates it in the vertical direction, and channels it into the lens, that is, the vertical space between the upper and lower grids. As the wave travels through, a focusing effect takes place; and the enhanced wave energy is coupled out and connected to coaxial line feeders of the hf receiver.

e. The logarithmically periodic array (the log-periodic antenna) is a highly directional, high-gain antenna. It can be erected in fixed azimuth configurations, or it can be compactly constructed to be rotated on a mast. It has many desirable characteristics for hf communication service. See figure 2-21. Granger Associates Model 2731-3K rotatable log-periodic antennas (not illustrated) have been procured for hf applications by the FAA. These antennas cover the band 4MHz to 30MHz and can handle 2.5kW of power. The tower height is 100 feet (30.48 meters), and 360° rotation is accommodated.

f. The familiar Yagi antenna is often used in hf communication. While it is not normally constructed as a broadband antenna the elements of the Yagi can be modified for limited band harmonic operation. It is small enough to be rotated and provides good gain and directivity on a narrow band of frequencies. One multiband model is shown in figure 2-22.

g. Another rotatable antenna is the quad (short for cubicle quad). A commercial model quad is shown in figure 2-23. It is basically two square-loop antennas spaced 0.15 to 0.2 wavelengths apart, with a leg dimension of 0.25 wavelength. One of the loops is driven by the transmitter, while the other

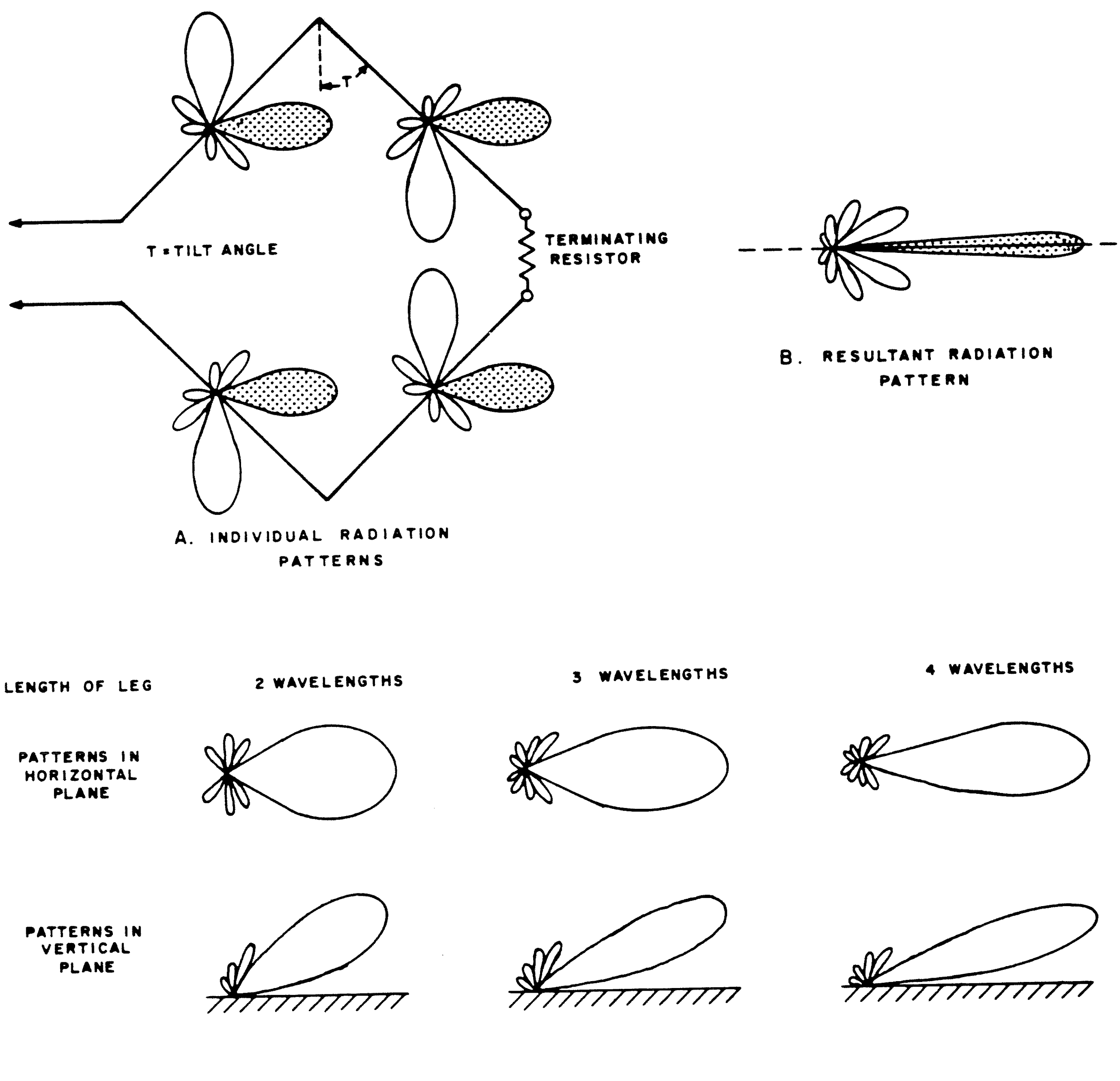
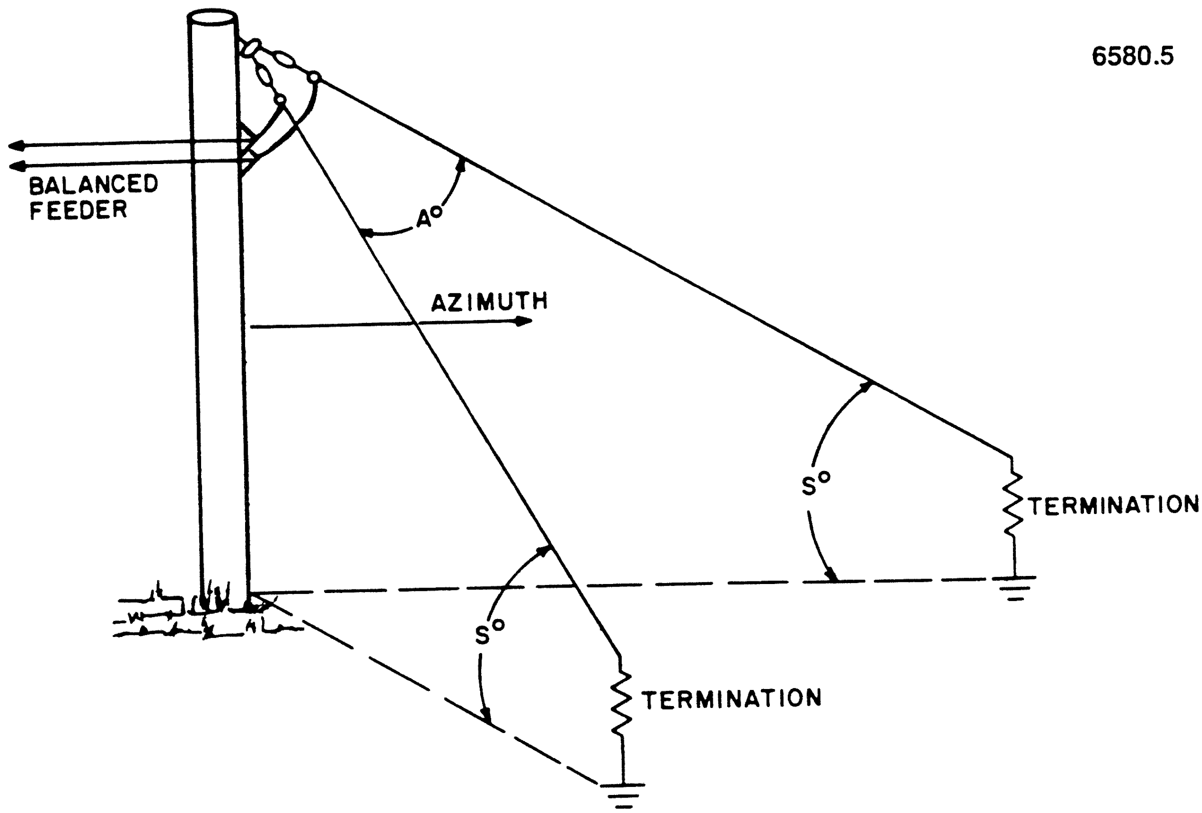


Figure 2-17. Typical Rhombic Antenna Horizontal and Vertical Plane Radiation Patterns



NOTE : THE AZIMUTH BISECTS VERTEX ANGLE A°. SLOPE ANGLE S° DETERMINES SKYWAVE TAKEOFF ANGLE.

Figure 2-18. Terminated Sloping V Antenna

acts as a parasitic reflector. The gain of the quad is roughly equivalent to a three-element Yagi.

h. The vertical monocone antenna is omnidirectional and broadband and has little or no gain relative to a dipole. Its principal application is ground-to-air (g-a) voice broadcast. The broadband characteristic is derived from its conical cross section. Granger Associates Series 1794-5K monocone antennas have been procured for FAA hf circuits, for hf broadcast applications. The frequency band covered is 2.8MHz to 32MHz, and the power-handling capability is 5kW. The overall height is 61 feet (18.7 meters); the diameter at the largest cross-section is 90 feet (27.6 meters). See figure 2-24 for details.

i. A loop antenna of special design by Technical Communications International (TCI) is in use on the island of Guam as an a-g receiving communication antenna. See figure 2-25.

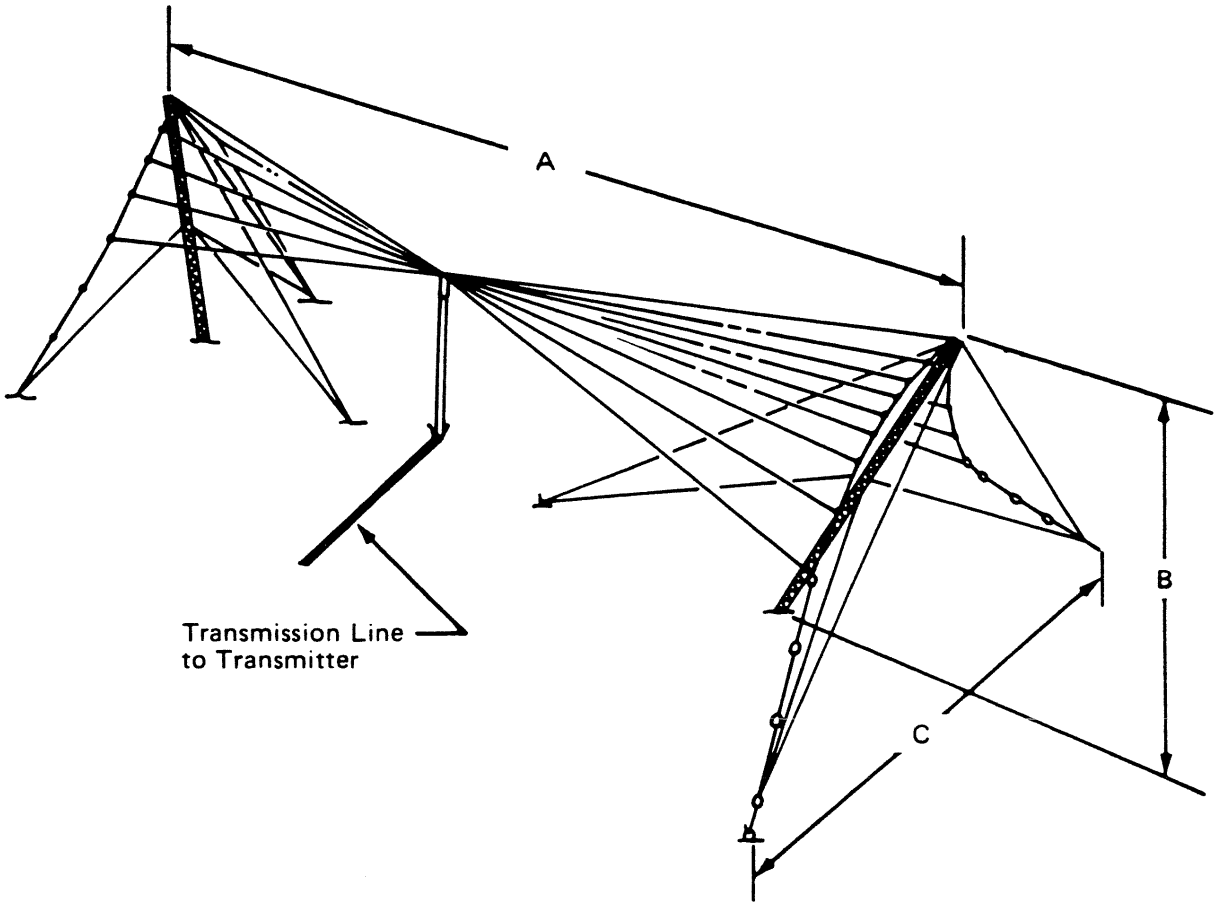
48. GROUND-MOBILE ANTENNAS.

Base-station and vehicular-mounted antennas are used in the 1.5MHz to 30MHz hf bands when necessary to communicate over relatively long distances between a fixed station and vehicles. The lower high frequencies are useful when terrain is rugged and line-of-sight is not possible.

a. Base-Station Antennas. Base-station antennas are of several kinds. The most common are vertical masts and whips. The quarter-wave ground plane antenna is useful for short-haul hf groundmobile operation. Figures 2-26 and 2-27 illustrate several types of hf base-station antennas. In the lower frequency bands, vertical polarization is mandatory, for it provides protection from horizontally polarized electrical noise that otherwise would render communication impossible.

b. Vehicular-Mounted Antennas. The most common type of vehicular-mounted antennas in the hf bands is the whip antenna, illustrated in figure 2-28, part A. The whip is a thin, flexible radiator usually operated and tuned as a grounded vertical antenna. The antennas may range in length from about 1 foot (0.3m) to over 20 feet (6m). They are constructed of steel, aluminum, or Monel metal tubing, usually in telescoping sections. The base may be spring-loaded to permit tiedown of the whip while the vehicle is in motion. The whip antenna has an omnidirectional pattern. The pattern will be somewhat distorted because of the proximity of the body of the vehicle. It is seldom practical for a vehicular antenna to be directional in characteristic. Part B of the figure is a roof-mounted stub, usually used at frequencies above 100MHz.

49.-50. RESERVED.



Model Number	Frequency Range	DIMENSIONS					
		Feet			Meters		
		Length (A)	Height (B)	Width (C)	Length (A)	Height (B)	Width (C)
1765-20-*K	2.0 to 30 MHz	185	68	134	56.4	20.7	40.8
1765-21-*K	2.4 to 30 MHz	160	59	116	48.8	18	35.4
1765-22-*K	3.4 to 30 MHz	115	41	81	35	12.5	24.7
1765-23-*K	4.3 to 30 MHz	90	32	62	27.4	9.8	18.9

Figure 2-19. Multiwire Broadband Antenna

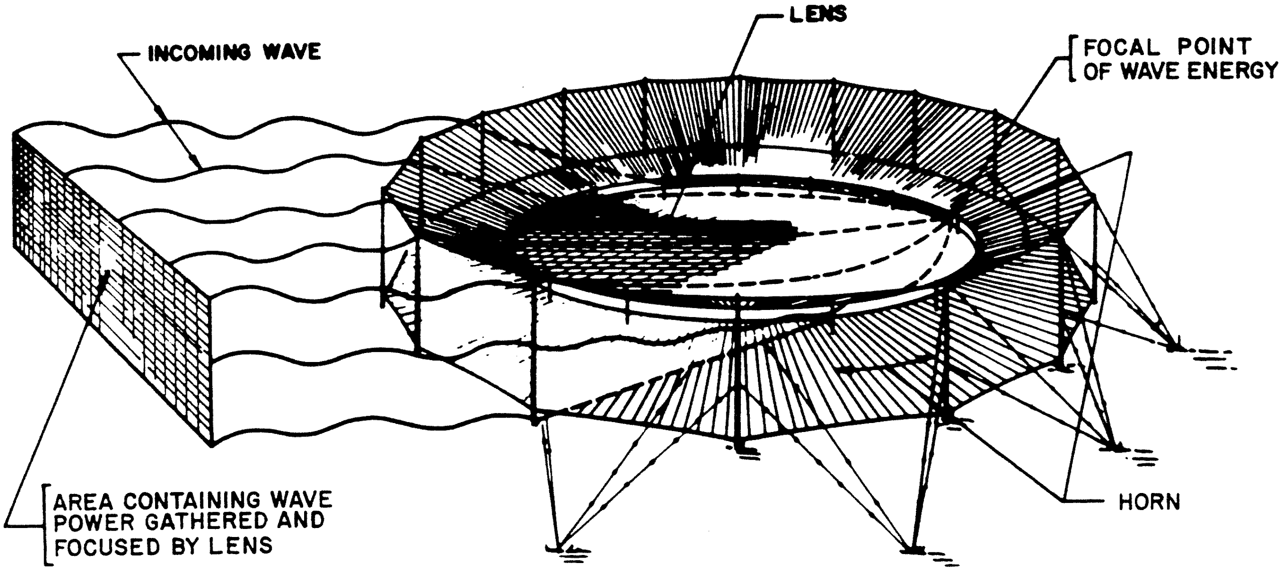


Figure 2-20. Tanner Wire-Grid Lens Antenna

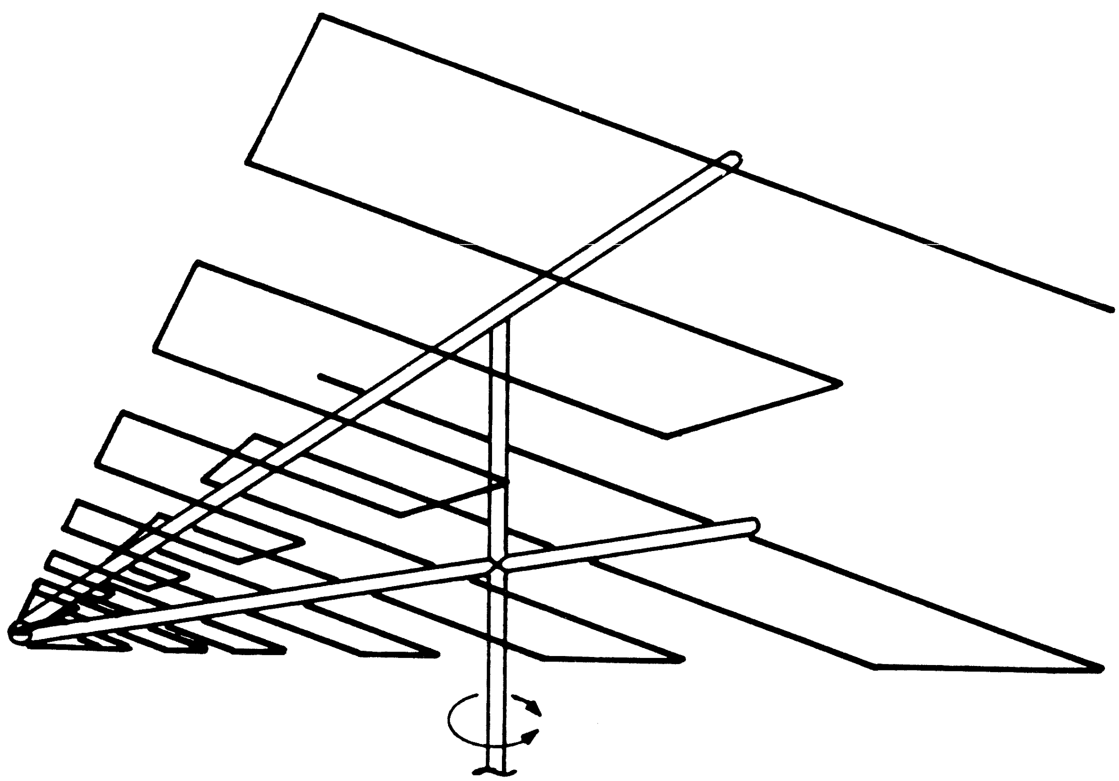


Figure 2-21. Rotatable Log-Periodic Antenna

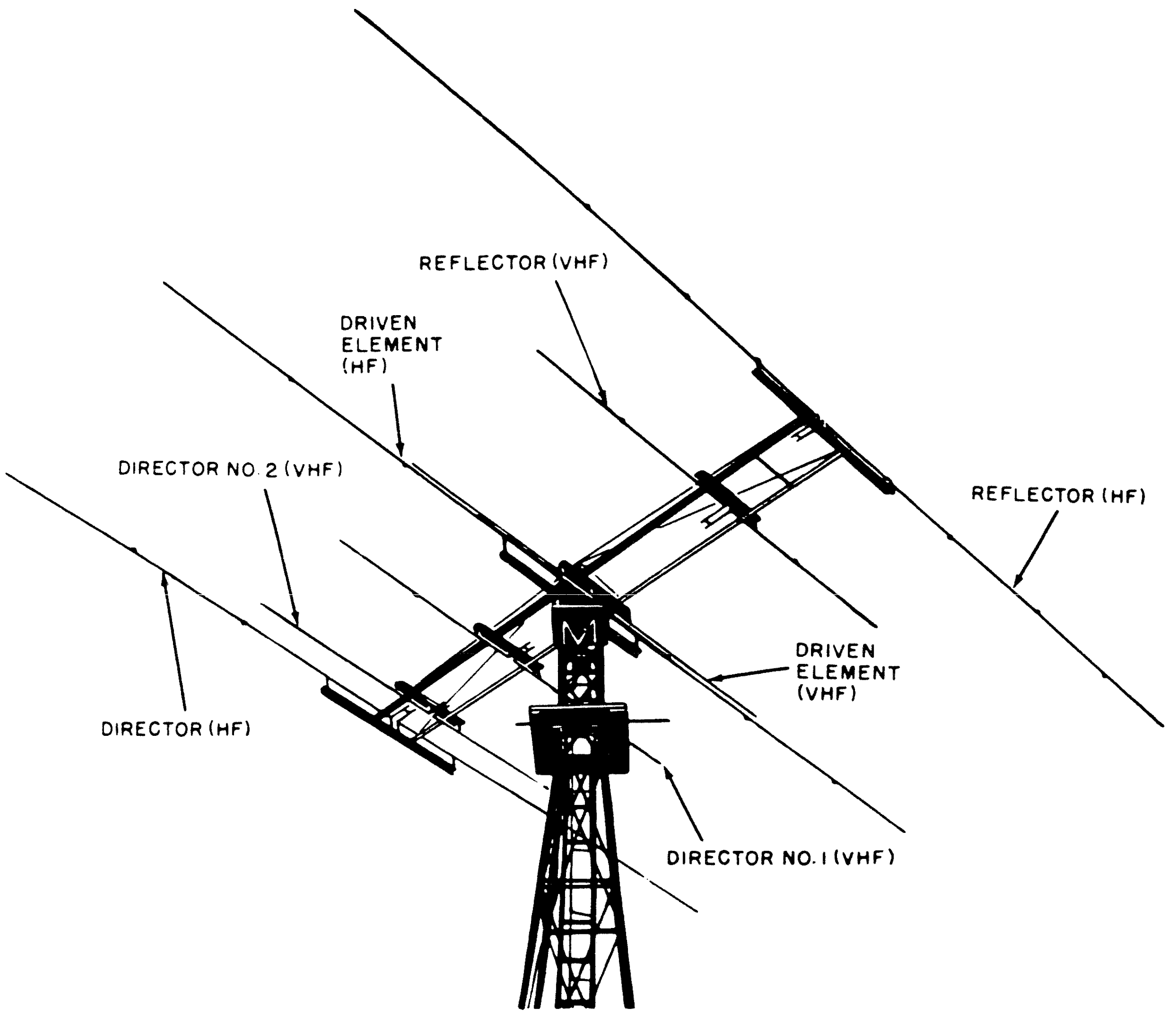


Figure 2-22. Rotatable Yagi Antenna

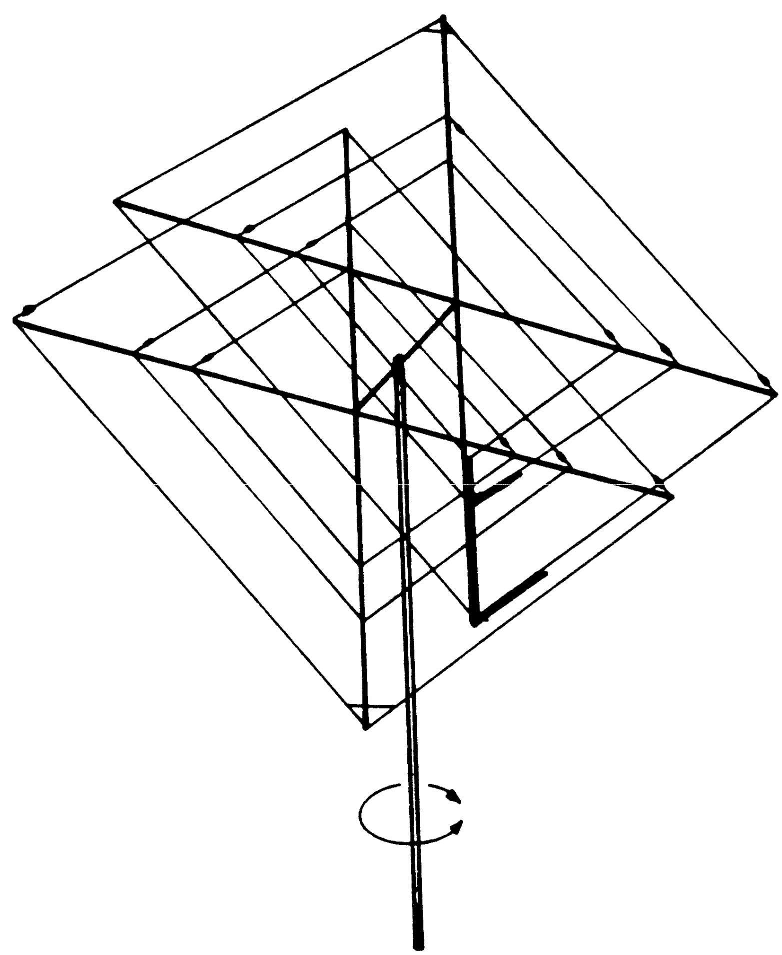
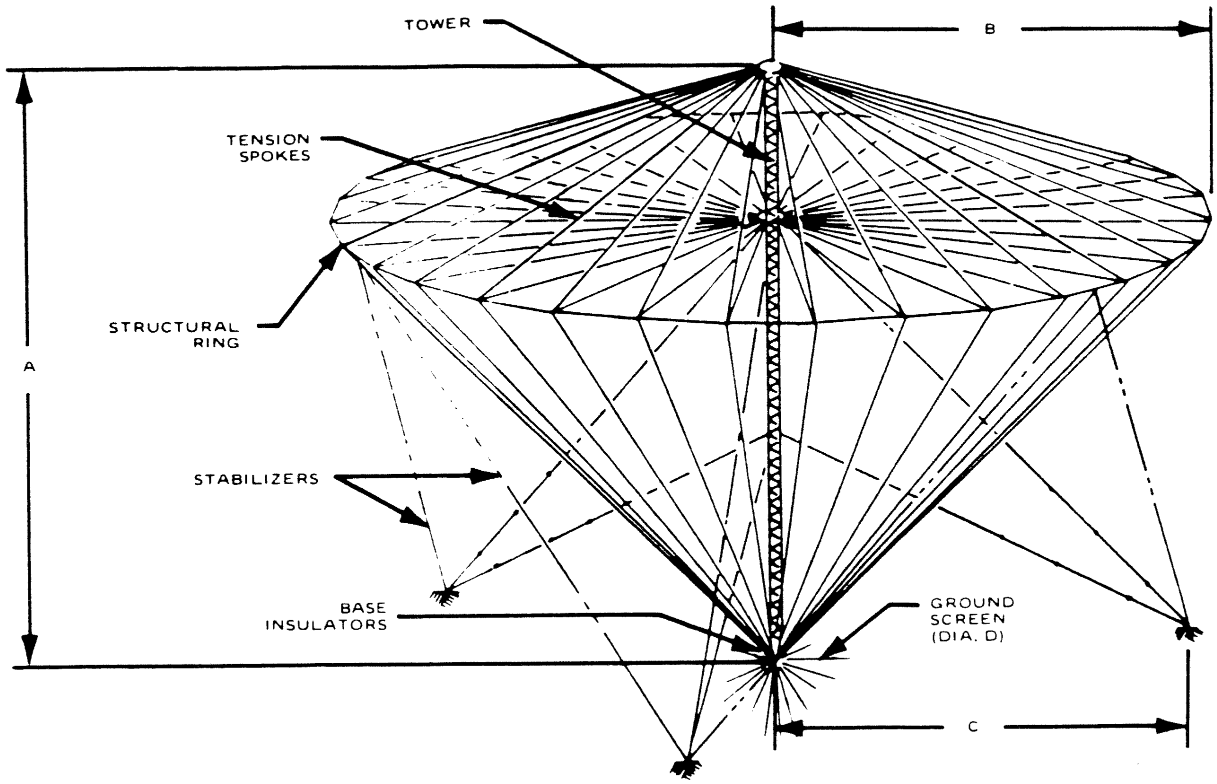


Figure 2-23. Rotatable Cubical Quad Antenna



Model Number	Weight		Volume		A		B		C		D	
	lbs	kg	cu ft	cu m	ft	m	ft	m	ft	m	ft	m
1794-1K, 2K	3250	(1472)	120	(3.40)	86	(26.3)	63	(19.3)	60	(18.4)	246	(75.3)
1794-3K, 4K	2700	(1223)	110	(3.11)	71	(21.7)	52	(15.9)	49	(15.0)	205	(62.7)
1794-5K, 6K	2200	(997)	90	(1.04)	61	(18.7)	45	(13.8)	42	(12.9)	176	(53.8)
1794-7K, 8K	1400	(634)	70	(1.98)	43	(13.2)	32	(9.8)	29	(8.9)	123	(37.6)
1794-9K, 10K	1100	(498)	65	(1.84)	31	(9.5)	23	(7.0)	19	(5.8)	88	(26.9)

Figure 2-24. Vertical Monocone Antenna

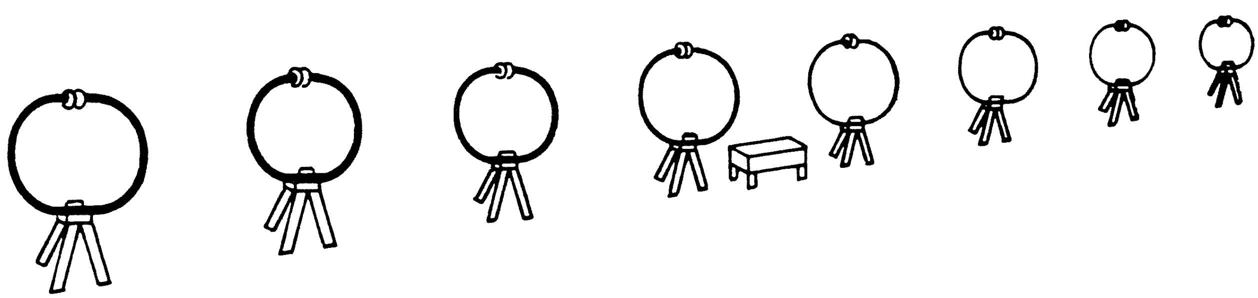


Figure 2-25. HF Loop Antenna Array

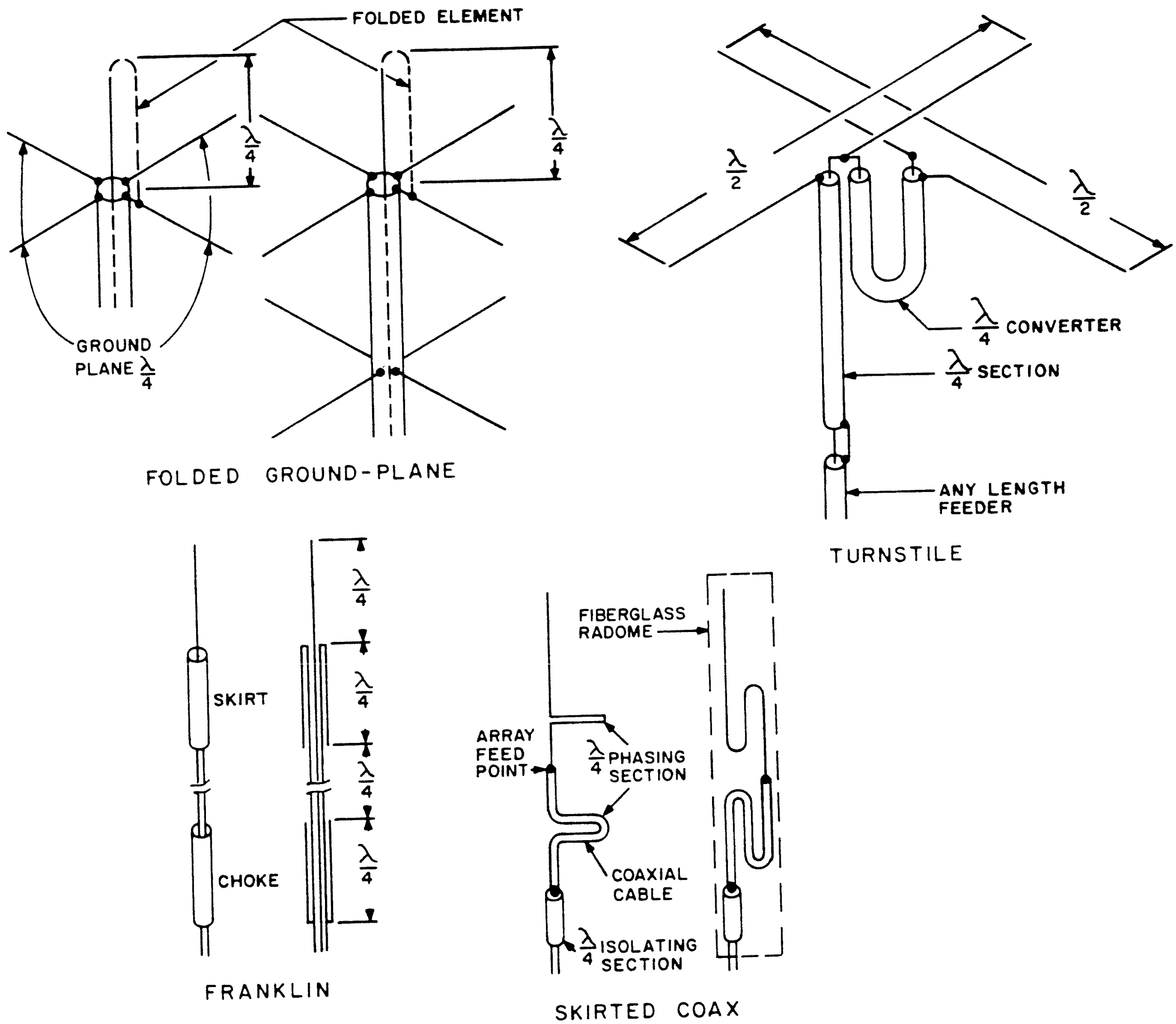


Figure 2-26. Omnidirectional Base-Station Antennas

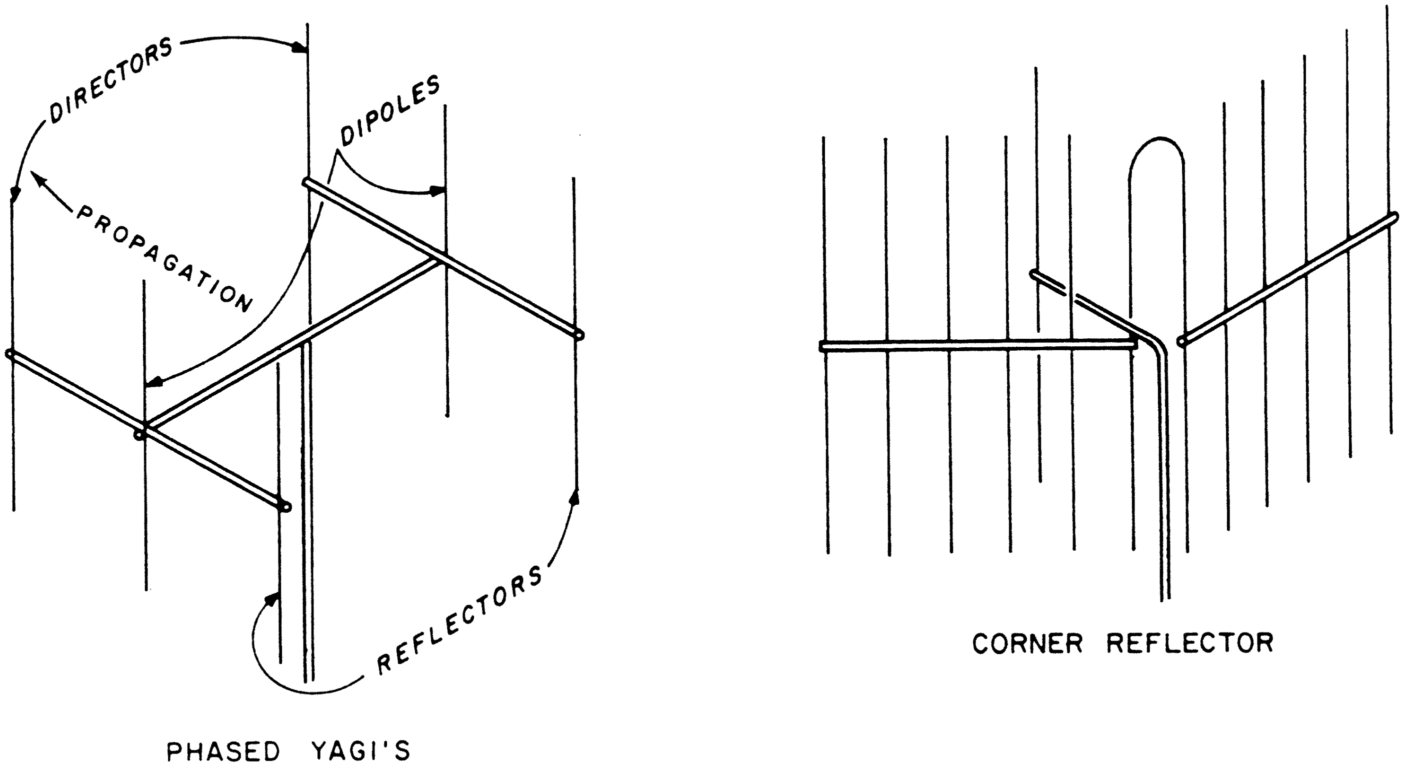


Figure 2-27. Directional Base-Station Antennas

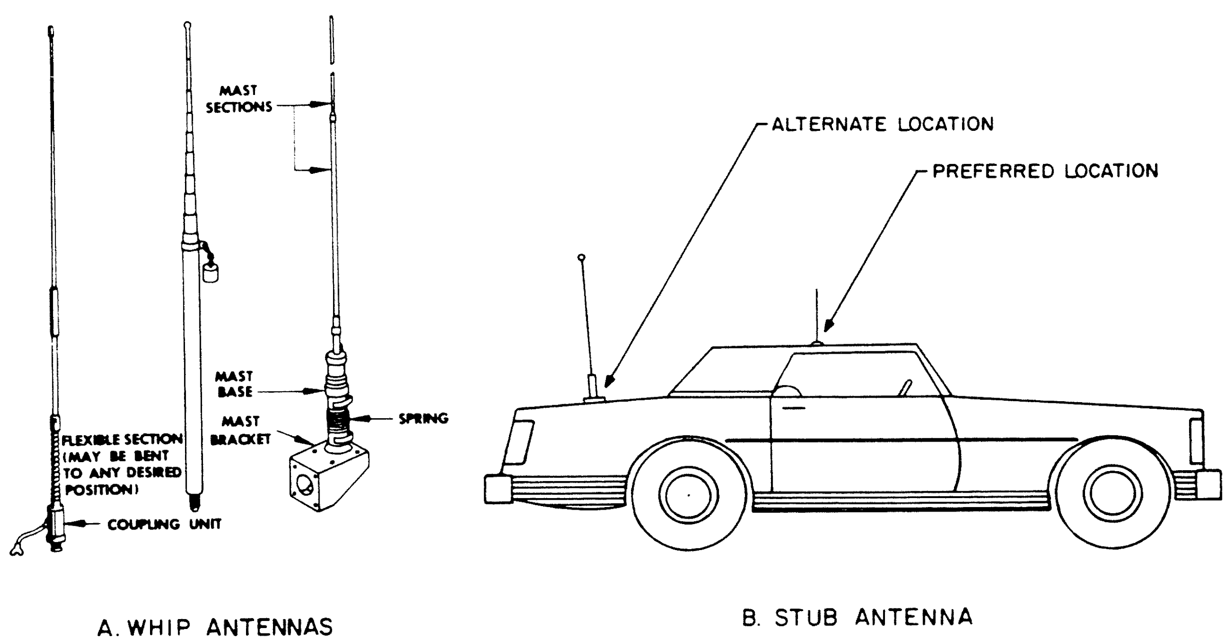


Figure 2-28. Vehicular-Mounted Whip and Stub Antennas

Subsection 4. WAVE PROPAGATION

51. GENERAL.

A brief discussion of radio wave propagation at hf frequencies is included in this section. The geometry of propagation in the hf frequency band used by the FAA is discussed, including certain propagational disturbances having the greatest effect on the reliability of FAA radio communication.

52. BASIC.

Point-to-point and broadcast hf communication circuits use 3 to 30 MHz frequencies that are able to be propagated over many thousands of miles by reflections from the earth's ionosphere. Such reflections (actually refractions) take place a number of times on the long-haul circuits, following a great-circle path. Ionization of the ionosphere, usually by the sun's ultraviolet radiation, provides varying degrees of penetration and absorption. For each frequency incident on a layer as a skywave there is a critical frequency above which the energy penetrates and does not return to earth. The critical frequency is important for predicting the behavior of the ionosphere and, consequently, the efficiency of multihop radio transmission. The orientation of the transmitting antenna that places its main lobe of radiation on the great-circle azimuth of the distant station is obtained by trigonometric calculations. Examples are given in appendix 2. Figure 2-29 depicts three typical great-circle paths and the spherical triangles used for calculations.

53. STRUCTURE OF THE IONOSPHERE.

There are four distinct ionic layers of the ionosphere as shown in figure 2-30.

a. D Layer. This layer is not always present, but when it does exist, it exists only in the daytime and is between 31 and 56 miles (50 and 90 kilometers) above the earth, being the lowest of the four layers. This region is so highly ionized that little or no skywave reflection is obtained from it; the wave is usually totally absorbed.

b. E Layer. This layer exists only during daylight hours between 56 and 87 miles (90 and 140 kilometers) above the earth. This layer depends solely upon ultraviolet radiation from the sun. Since the E layer depends directly upon the sun, it is most dense directly under the sun. Seasonal variations occur in this layer because the sun's zenith angle varies seasonally. Shortly after sunset the layer disappears. Because E layer density follows the sun, points of equal latitude have the same E layer conditions at the same local time.

c. The F Region. The F region includes the F1 and F2 layers, which have differing altitudes, durations, and responses to solar radiation. The F2 layer is of greatest importance to long-haul multihop radio links.

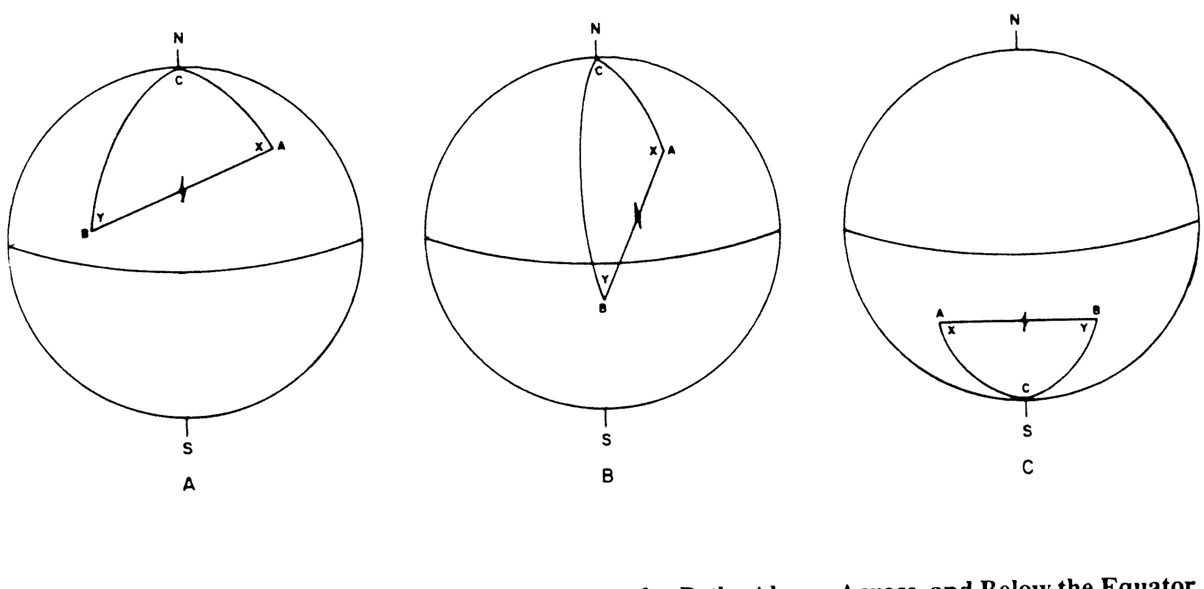


Figure 2-29. Typical Great-Circle Spherical Triangles for Paths Above, Across, and Below the Equator

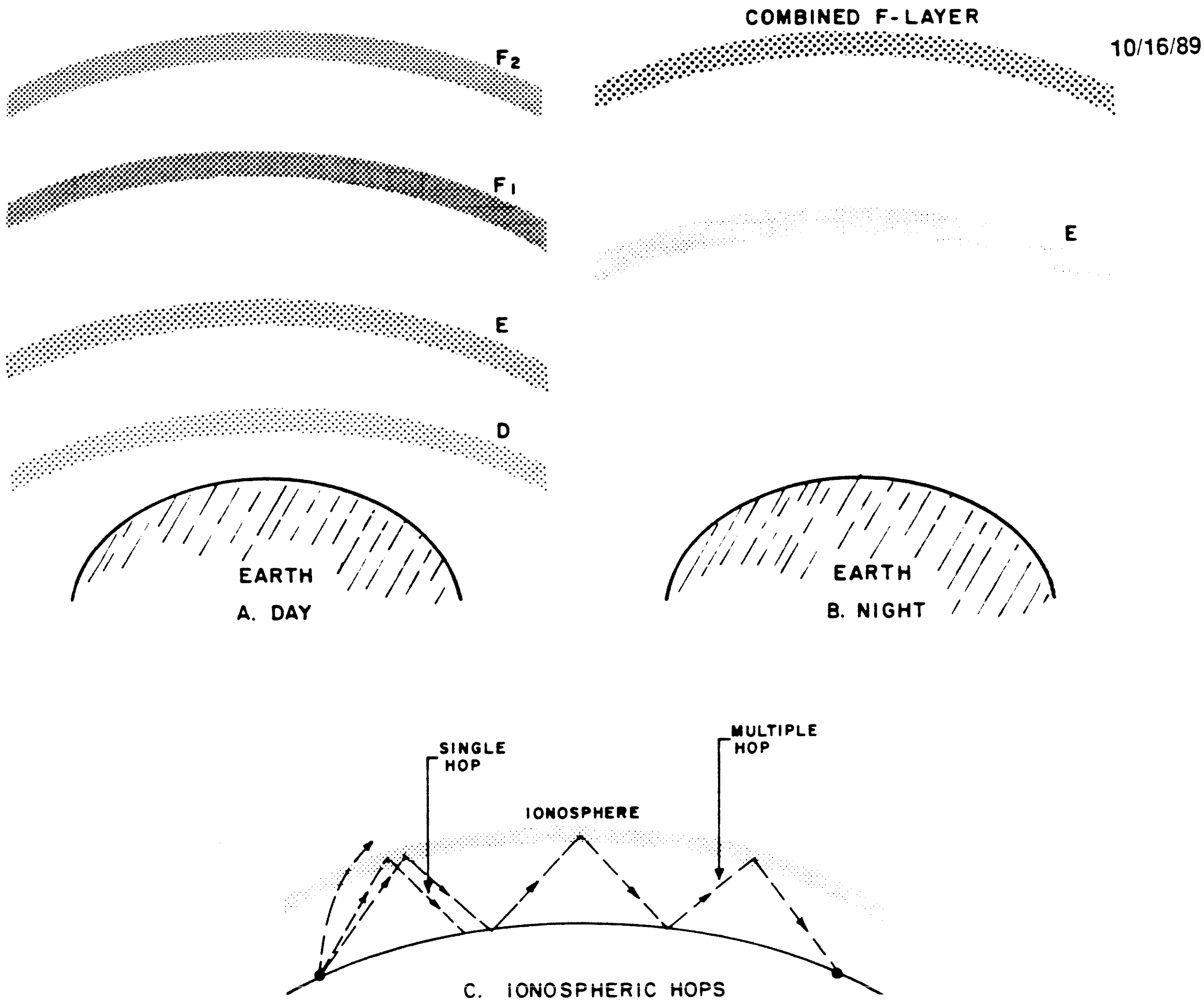


Figure 2-30. The Four Principle Layers of the Ionosphere

(1) **F1 Layer.** The F1 layer exists between 87 and 155 miles (140 and 250 kilometers) above the earth during daylight hours. This layer behaves like the E layer during daylight; that is, it follows the sun. When the sun sets, the F1 layer rises to merge with the next higher ionic layer, the F2 layer.

(2) **F2 Layer.** Of all the ionized layers, the F2 layer is the most important for long-range PTP and a-g communication. It is the most predictable layer, and for the purpose of maintaining 24-hour hf circuit continuity, the National Bureau of Standards (NBS) issues short- and long-term hf prediction bulletins based on the F2 layer. These bulletins are issued through the institute for Telecommunications Sciences and Aeronomy (ITSA) to subscribers around the world, including the FAA.

(a) The F2 layer is the most useful ionic layer for skywave transmission because of its height and because it exists during the night as well as during the day. This layer is between 93 and 155 miles (150 and 250 kilometers) above the earth during the night for all seasons of the year. During the day in the summer it is between 155 and 177 miles (250 and 285 kilometers) high, and during the day in the winter it is between 93 and 177 miles (150 and 285 kilometers) high. This variation in height is accounted for by the effect of solar heat on the layer, which increases its height and decreases its ion density during the summer. The reduction of solar heat in the late afternoon causes the layer to descend. No complete explanation has been made for the existence of the F2 layer, but it is known that it is considerably affected by particle radiation from the sun, evidenced by the strong influence that the earth's magnetic field has on the distribution of the F2 layer.

(b) The effect of the earth's magnetic field results in the greatest ion density, and the highest critical frequency, in a region about 20° from the magnetic poles, rather than directly under the sun as in the case of the D and E layers.

Since the earth's magnetic field is not evenly distributed, longitudinal variations exist in the F2 layer for points of equal latitude at the same local time. For this reason, the earth is divided into three zones that represent different degrees of magnetic intensity to facilitate plotting F1 layer distribution. These zones are called the east, west, and intermediate zones. Monthly predictions of F2 layer distribution are then made by NBS for each of the three zones.

54. SKYWAVE TRANSMISSION GEOMETRY.

Skywave propagation essentially follows optical laws of phases. If there were no disturbance (paragraph 56) affecting the stability of the layers of the ionosphere, the incident wave and the reflected wave of propagation would always have the same propagation angle of reception and transmission. A communication circuit established on such a path would have high reliability. The basics of skywave geometry are summarized in the following subparagraphs and are illustrated in the figures referenced.

a. Refraction Process. When skywave propagation is used for communication, the electromagnetic wave from the antenna is transmitted toward an ionic layer at an oblique angle. The incident wave then appears to be reflected, at the same oblique angle, from the ionic layer back toward the receiving antenna. Actually, the wave is not reflected; it is bent back toward the earth by refraction, just as a prism refracts light. The bending process is a function of the refractive index of the ionic layer and behaves in accordance with optical geometry. Roughly stated in terms of ionospheric refraction of a radio wave, this law is as follows: For a wave incident upon a densely ionized layer to be bent back toward the earth, the wave must pass from a medium with a high refractive index to a medium of low refractive index.

b. Critical Frequency. A vertically transmitted frequency greater than the critical frequency will penetrate the ionosphere, while a frequency less than this value will be reflected. When the critical frequency (f_o), for the ionosphere over a certain point is known, the frequency (f), which will just be reflected by the ionosphere over that point, can be calculated by: $f=f_o \csc \Delta$. This is the maximum usable frequency (muf) for the vertical radiation angle Δ. Frequencies above the muf will penetrate the ionosphere; frequencies below the muf will be reflected and become hops, as shown in figure 2-31. The muf can be determined for any distance, geographic location, sunspot number, or time of day.

c. Maximum Usable Frequency (MUF).

(1) The muf is the upper limiting frequency at which a communication circuit may be operated. The muf, as determined from available ionospheric predictions, is actually a monthly median of the highest usable daily frequencies for a particular skywave path at a particular hour of the day. The geographic location of reflection points, the time of day, season, and sunspot number all affect the muf. The muf for path lengths less than 2,480 miles (4000 kilometers) is determined by the ionospheric conditions at the midpoint of the path. It is taken as the highest of the three maximum frequencies, which will be reflected from the E layer, sporadic E layer, or F2 layer. The charts of median zero muf and median 4000 muf predicted for the proper month, from the NBS, are used to determine the muf for a given communication link.

(2) The muf represents the median maximum usable frequency. That is, 50 percent of the days the actual muf will be less than the median muf, and 50 percent of the days the actual muf will be greater than the median muf. For this

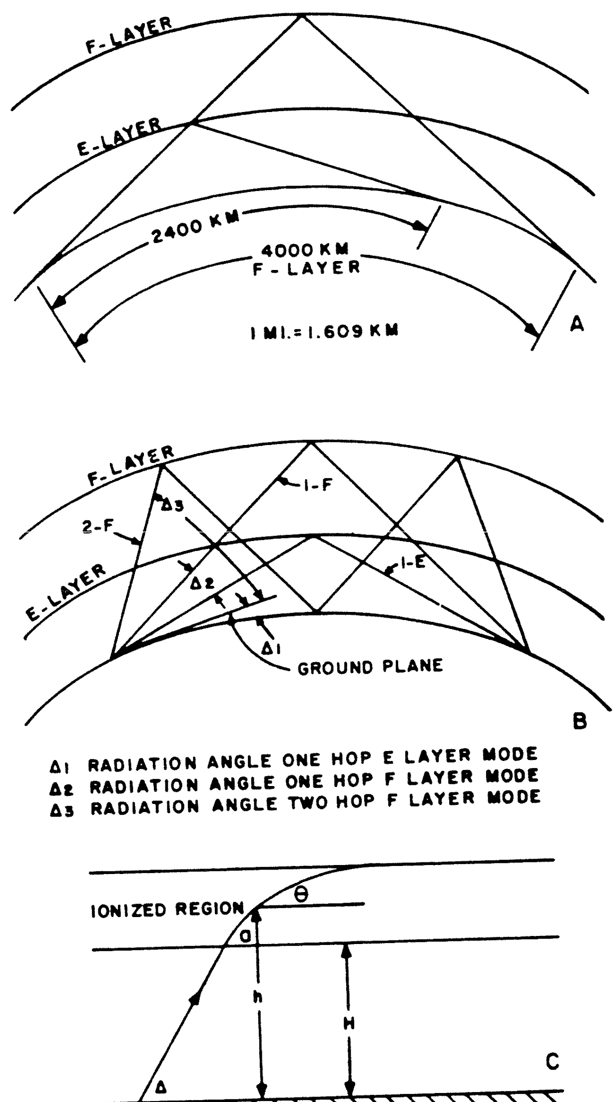


Figure 2-31. Geometry of Ionospheric Propagation

reason, it is desirable to operate a circuit at a frequency that is slightly less than the median muf to increase communication reliability. Where F2 propagation is used, this frequency of optimum operation (fot) (sometimes owf for optimum working frequency) is taken as 85 percent of the muf. Where E and F1 propagation is used, the fot is taken as the muf for E propagation, because the muf variation from day to day is too small.

d. Lowest Usable High Frequency (LUHF). The luhf (sometimes luf for lowest usable frequency) is the lower limiting frequency that will provide satisfactory communication for a given link. The luhf is the frequency at which the received field intensity just equals the required field intensity for reception. The received field intensity depends on the antennas, path length and absorption; and it generally increases with frequency. The required field intensity for reception depends on noise limitations, and it decreases with frequency. Therefore, by comparing the received median field intensity at various frequencies with the required field intensity for the same frequencies, the luhf is determined.

55. GROUNDWAVE AND SCATTER PROPAGATION.

a. Groundwave Paths.

(1) Groundwave propagation is propagation of rf energy along the curved surface of the earth, without using the earth's ionosphere. Where a groundwave is transmitted beyond the line of sight, the conductivity of the earth's surface acts as a waveguide and bends the wave around the curved surface. Since fading is due primarily to ionospheric fluctuations, there is no fading associated with groundwave propagation. However, the extremely high losses associated with groundwave depends upon the type of terrain over the transmission path, the transmitting and receiving antennas, the power output, frequency, and antenna heights.

(2) Only vertical polarization, such as is obtained from vertical and whip antennas, is practical for groundwave propagation. Horizontal polarization results in extremely high losses due to a short-circuiting effect of the earth. Even with vertical polarization, the received field intensity of a groundwave is far below that of the direct, free-space field. The antenna height also affects groundwave propagation.

(3) For line-of-sight transmissions, the received field intensity is composed of a direct wave and a ground-reflected wave. If the two received waves are about 180° out of phase, the received signal level will be very low. Conversely, if the two received waves are in phase, the received signal will be almost twice as strong as the signal resulting from the direct wave. Therefore, for line-of-sight transmissions, the received signal level varies from near zero to twice the signal resulting from the direct wave, depending upon the transmission path length.

b. Forward Scatter. Within the past 30 years, successful and highly reliable forward-scatter propagation has been used for multichannel rtty and voice communication. Techniques were developed for detecting extremely small rf signals in the presence of cosmic noise. Circuits have been tested in both ionospheric scatter (20 to 60 MHz) and tropospheric scatter (60 to 1000 MHz) modes for ground-to-ground and air-to-ground communication. Forward-scatter antennas are not included in this order.

56. IONOSPHERIC VARIATIONS.

Refer to tables 2-1 and 2-2 for regular and irregular variations of the ionosphere.

a. Sunspots. The sun is the major source of energy that produces ionization of the earth's atmosphere. Therefore, any solar disturbance produces variations in the ionic layers. Sunspots are evidence of such solar disturbances that affect the ionic layers. These sunspots appear as dark patches surrounded by a hazy gray edge and are presumably vortexes of enormous gas clouds. These gaseous clouds produce vast amounts of ultraviolet energy that affect the ionization of the earth's atmosphere. Therefore, the greater the number of sunspots, the greater the ultraviolet radiation and the greater the ionization. For this reason, the number of sunspots is indicative of ion density, which, in turn, is a measure of the probability of skywave communication. Sunspot activity is measured by the Wolf sunspot number method, which considers not only the number of actual sunspots but also the number of sunspot groups. Observations of solar activity over the past 100 years have confirmed that sunspot activity is cyclic, the cycle repeating every 11.1 years. There are variations within this cycle and variations from cycle to cycle that make it necessary to know the predicted sunspot number for a given time in order to determine the probability of skywave communication.

b. Sudden Ionospheric Disturbances (SID's). Occasionally daytime communication by high-frequency skywave propagation is lost by abnormally great absorption. The onset of this condition is usually very sudden with recovery being more gradual, and the condition may last from a few minutes to several hours. This condition is known as solar flare disturbance, Delligner fade, or most commonly, sid. The result of an sid is a sudden increase in the ion density of the highly absorptive D region, as well as an increase in the ion density of the moderately absorptive E layer.

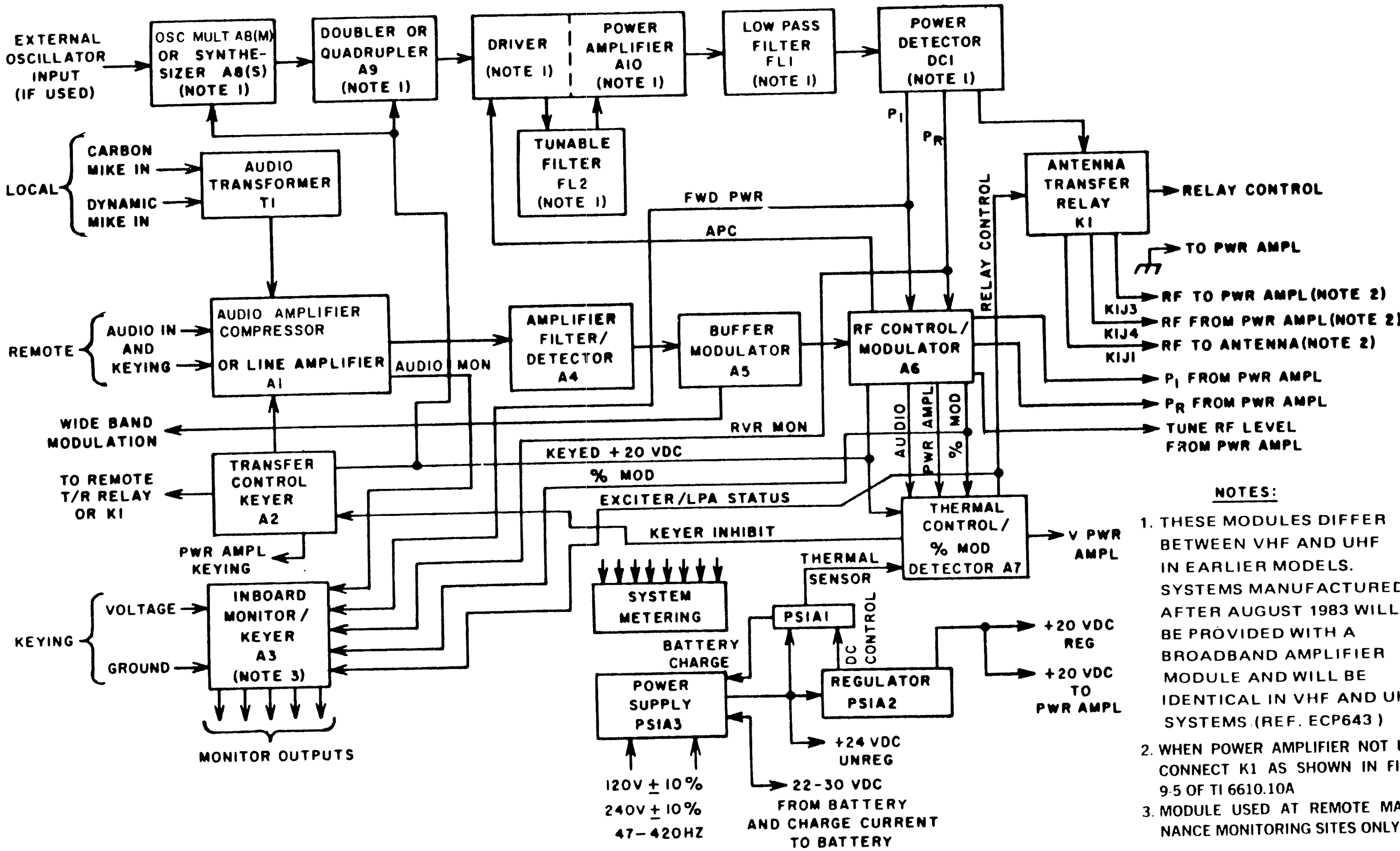
c. Magnetic Storms. Magnetic storms are not the same as sid's, although they both have the same effect in that they reduce the probability of communication by skywave propagation. The magnetic storm is associated with solar ac-

Table 2-1. REGULAR VARIATIONS OF IONOSPHERE

Type of Variation	*Effect on Ionosphere*	*Effect on Communication*	*Method of Compensation*
11-YEAR SUNSPOT CYCLE	F_1 and F_2 layers particularly increase in density and height in direct accordance with sunspot activity (maximum activity, minimum activity.)	Higher critical frequencies during years of maximum sunspot activity. Higher maximum unusable frequencies during high sunspot activity.	Use higher operating frequencies for long-distance communication during periods of sunspot maximum, say 19 to 35MHz. Use lower frequencies during minimum, say 5 to 20MHz. Consult predictions to determine maximum usable frequencies.
27-DAY SUNSPOT	Recurrence of sudden ionospheric disturbances and storms at 27-day intervals. Disturbed condition frequently identified with very active sunspots whose radiations are directed from the sun every 27 days as the sun rotates.	See effects of sid's and ionospheric storms in Table 2-3, Irregular Variations of Ionosphere.	See compensation for sid's and ionospheric storms in Table 2-3, Irregular Variations of Ionosphere.
DIURNAL (variation with time of day)	**F** layer: Density and height decrease at night, increase after dawn. During day layer splits into: (1) F_1 layer whose density follows vertical angle of sun, (2) F_2 layer whose density increases until later in the day and whose height increases until noon. **E** layer: Density follows vertical angel of sun, height approximately constant. Practically disappears at night. **D** layer: Appears after dawn, density follows vertical angle of sun, disappears at night.	Skip distance varies below 30MHz. Absorption increases during day.	Use higher medium frequencies during day, lower medium frequencies at night.
SEASONAL	F_2 layer height increases greatly in summer, decreases in winter. Ionization density rises earlier in winter and reaches higher value. Minimum pre-dawn density reaches lower value in winter. F_1, **E**, and **D** layers reach lower maximum densities in winter.	Wider range of critical frequencies in winter. Maximum usable frequencies are higher at midday in winter, but high values maintain later into afternoon in summer. Pre-dawn fall in maximum usable frequencies are lower in winter. Less absorption occurs in winter.	Use greater difference in night time and daytime operating frequencies in winter than in summer. Use medium high frequencies for long-distance winter communication and lower high frequencies for medium-distance communication.

TABLE 2-2. IRREGULAR VARIATIONS OF IONOSPHERE

Type of Variation	*Effect of Ionosphere*	*Effect on Communication*	*Method of Compensation*
SPORADIC E LAYER	"Clouds" of abnormal ionization occurring in the **E** layer or slightly above for a large portion of time each month result in abnormally high critical frequencies. Usually spotty in geographic extent and time.	Excellent transmission within normal skip distance. Occasionally, long-distance communication on frequencies of 60MHz and above.	Frequency may have to be lowered to maintain short-skip communication. At times, long-distance communication on abnormally high frequencies is possible.
SUDDEN IONOSPHERIC DISTURBANCE (SID)	Unusually high radiation from solar flare produces abnormally high ionization in all layers. Increase in ionization occurs very suddenly throughout daylight portion of earth.	Normal frequencies above 1 or 2 MHz are made useless because of high absorption in heavily ionized **D** layer. Considerably higher frequencies may not be absorbed for short-distance communication. Low frequencies may not penetrate the **D** layer, hence they may be transmitted for long distances.	Raise working frequency above normal for short-distance transmission and lower frequency below normal for long-distance transmission.
IONOSPHERIC STORMS	Accompanies magnetic disturbances occurring about 18 hours after SID's. Upper ionosphere expands and diffuses; critical frequencies are below normal; virtual heights are above normal. Severe effects near poles, decreasing toward equator. Duration from few minutes to several hours; effects disappear gradually in a few days.	Limits number of usable high frequencies.	Use frequencies lower than normal, especially in high latitudes.
SCATTERED REFLECTIONS	Irregularities in density of layers but heights normal.	Fading of signals due to arrival of signals from slightly different directions with varying phase relations.	None. Usually fading is of short duration.



NOTES:

1. THESE MODULES DIFFER BETWEEN VHF AND UHF IN EARLIER MODELS. SYSTEMS MANUFACTURED AFTER AUGUST 1983 WILL BE PROVIDED WITH A BROADBAND AMPLIFIER MODULE AND WILL BE IDENTICAL IN VHF AND UHF SYSTEMS (REF. ECP643)
2. WHEN POWER AMPLIFIER NOT USED, CONNECT K1 AS SHOWN IN FIGURE 9-5 OF TI 6610.10A
3. MODULE USED AT REMOTE MAINTENANCE MONITORING SITES ONLY

Figure 2-32. Block Diagram of the AN/GRT-21 (VHF) and AN/GRT-22 (UHF) Transmitters, 10-Watt its output signal goes to the power amplifier. The tunable filter is placed between the last two stages of the driver.

e. Tunable Filter, FL2. The tunable filter reduces harmonics and noise generated in the driver.

f. Power Amplifier, A10A2, -A3, -A4, -A5, -A6. The vhf power amplifier linearity amplifies the signal from the tunable filter to a minimum level of 10W. The uhf power amplifier consists of three power amplifiers (A102A, A103A, A104A), a hybrid (A106A), and a hybrid detector (A105A). The combination forms a linear amplifier that increases the modulated signal from the driver to a minimum level of 10W.

g. Low-Pass Filter, FL1. The low-pass filter following the power amplifier suppresses harmonics generated in the final stages of the power amplifier.

h. Power Detector, DC1. The power detector detects forward and reverse power and delivers this information to the rf control and modulator board (A6).

NOTE: Hardware delivered from the factory after August 1983 contains redesigned driver-power amplifiers that are broadband and may be used interchangeably between vhf and uhf exciters. The new driver power amplifier consists of four push-pull broadband amplifier stages with a minimum output of 10 watts.

i. Antenna Transfer Relay K1. The antenna transfer relay's function is to switch the rf power from the power detector to either the antenna or the power amplifier. When connected to the power amplifier, the relay connects the power amplifier to the antenna. It can also be used as the transmit-receive (tr) delay when the power amplifier is not used. Normally, there is a dedicated antenna element for the transmitter output.

j. Line Amplifier or Audio Amplifier Compressor, (A1(L). The audio amplifier compressor accepts the local or remote microphone input, amplifies it, and furnishes a constant voltage level to the amplifier filter detector. For those installations where compression is accomplished ahead of the transmitter input, a line amplifier A1(L) module is used in place of the compression amplifiers.

k. Transfer Control Keyer, A2. The transfer control keyer contains the circuitry necessary for keying various assemblies in the exciter and furnishes an inverted signal that may be used for keying the power amplifier rf output. It also supplies the dc voltage required to operate the carbon microphone and the dynamic microphone preamplifier.

l. Amplifier Filter Detector, A4. The amplifier filter detector performs two functions. The first is to pass frequencies in the 300Hz to 6kHz range with little attenuation and to attenuate signals outside of this range for application to the buffer modulator. The second function is to amplify the microphone inputs, local or remote, to provide the front panel meter with audio signal levels.

m. Buffer Modulator, A5. The buffer modulator has two circuits. The first provides amplification for the meter modulation signal; the second provides wide-band data input, a clipping level control, and limits to prevent overmodulation.

n. RF Control Modulator, A6. The rf control modulator assembly contains the circuitry required to provide modulation to the driver. It also limits the power level when high standing waves exist, maintains a constant power level, and logically determines if the power amplifier is operational or not; it then furnishes this information to the A7 control unit 1.

o. Control Unit, A7. This module contains circuitry to inhibit keying when excessive temperatures exist in the power supply and connects the exciter to the antenna whenever the power amplifier shuts down. It also contains the circuitry required to furnish percent modulation information to the meter.

p. Power Supply, PS1. The power supply module converts the 120V ac (or 140V ac) input power to both 28V dc unregulated and 20V dc regulated. It also supplies the battery, if connected, a charging current of 300mA at approximately 38V.

q. System Metering. The system metering function accepts the various test signals generated throughout the exciter as listed below.

(1) Relay voltage

(2) Forward power

(3) Reflected power

(4) Automatic power control (APC)

(5) Transmit-receiver relay

(6) Voltage-standing wave ratio (vswr)

(7) Rf output of power amplifier

(8) Filter tune

(9) Output of doubler or quadrupler

(10) Oven heater current

(11) Oscillator stage output

(12) Unregulated power supply voltage

(13) Battery voltage with power switch OFF

(14) +20V bus

(15) +20V bus current

(16) Keyed +20V

(17) Modulation index

(18) Modulation output from rf control modulator

(19) Output of amplifier filter

(20) Output of audio frequency (af) compressor

(21) Remote audio power level (–15 to +8dBm)

(22) Remote audio power level (–18 to -2.5dBm)

(23) Overtemperature sensing circuit

s. **Power Amplifier.** Figure 2-33, a functional block diagram of the power amplifier, includes the major subassemblies described below. The 50-watt power amplifier is a linear vacuum-tube amplifier, which raises the exciter's 10W output to a minimum level of 50W. When the ac power is interrupted, the exciter is automatically connected to the antenna and to an external dc power input, which provides a 10W output. The power amplifier is normally not authorized for use except for extreme coverage problems.

(1) **Tuned Cavity, A7.** The tuned cavity stage contains various subassemblies. The vacuum-tube amplifier, with input and output tuning, accepts the signal from the antenna transfer relay, and amplifies it to 50W level. The lowpass filter (FL2) suppresses harmonics generated in the power amplifier. The signal then passes through the power detector (DC1), which detects forward and reverse power and delivers corresponding dc levels to the buffer amplifier/electrical instrument multiplier. After passing through the power detector, the signal goes to the antenna via the antenna transfer delay.

(2) **Connector/Filter Assembly, A6.** The connector filter assembly provides connections and filtering for the various connections made to the tuned cavity (A7).

(3) **Buffer Amplifier/Electrical Instrument Multiplier, A5.** The buffer amplifier electrical instrument multiplier contains circuits for a buffer amplifier between the detectors from the power sensor and the rf control in the exciter. It also contains the system metering function, which monitors the following signals.

(a) Exciter on

(b) Exciter keyed

(c) Forward power

(d) Reflected power

(e) Plate supply voltage

(f) Plate current

(g) Screen supply voltage

(h) Control grid voltage

(i) Heater voltage

(j) High-voltage condition at power amplifier

(k) Fan voltage

(l) Overtemperature

(4) **Control Grid Power Supply/Control Circuitry, A3.** This module (A3) provides filament voltage, control grid voltage, and turn-off of amplifier if excessive temperatures exist in the tuned cavity or if the blower fails. It also contains the interlock circuitry for the cavity and high-voltage power supply.

(5) **Plate and Screen Grid Power Supply, A4.** A4 contains the circuitry to provide the screen grid with 390V dc and the plate with 24kV dc.

(6) **AC-to-AC Converter, A2.** The ac-to-ac converter converts the 60Hz input power to a 400Hz 110V signal to run the blower.

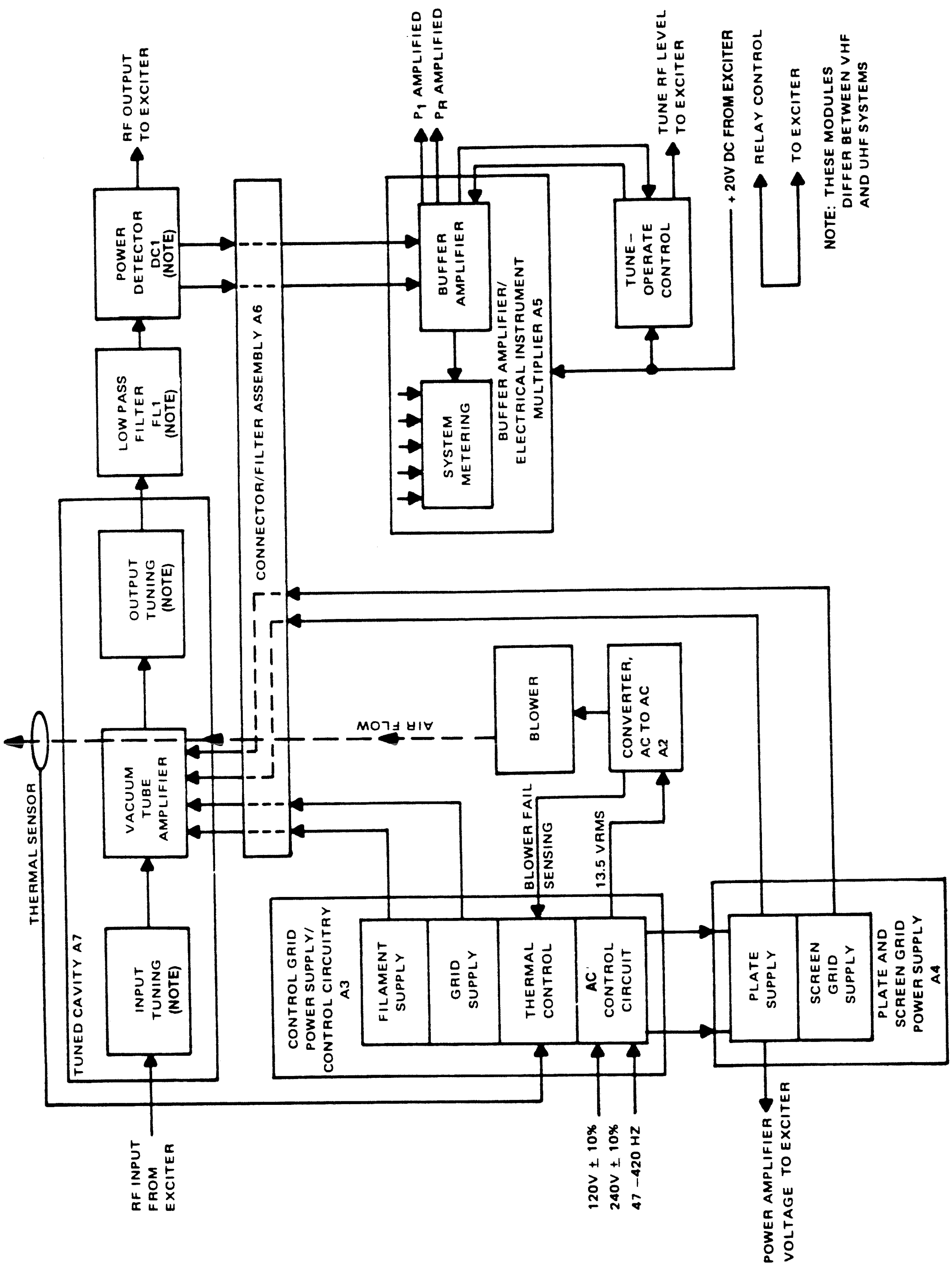


Figure 2-33. Block Diagram of the AN/GRT-21 (VHF) and AN-GRT (UHF) Linear Amplifier, 50-Watt

tivity, being more likely to occur during maximum sunspot conditions, and reoccurring in 27-day cycles, the rotation period of the sun. Magnetic storms are apparently caused by particle radiation from the sun, with the radiated particles being deflected by the earth's magnetic field. For this reason, the effects of a magnetic storm are most severe in the two geomagnetic pole regions. The origin of a magnetic storm may be the same solar eruption that produces an sid; but since particle radiation is much slower than ultraviolet radiation, the effect of the magnetic storm is not noticed until 18 to 36 hours after an sid. A magnetic storm has two phases. The first phase expands the F2 layer, which reduces ion density. During this phase, the F2 layer's critical frequency becomes lower than normal from reduced ion density. The second phase is marked by a greater concentration of electrons in the highly absorptive D and E regions, especially in the geomagnetic polar regions. The increased absorption that results may prevent communication by skywave propagation. A magnetic storm may last for several days, with its appearance being very sudden and recovery to normal very slow.

d. Sporadic E Layer. A sporadic E layer, abbreviated E_s, cannot be accounted for by the processes that explain the normal E layer, which exists at approximately the same height above the earth. It may be caused by particle radiation, or it may be a result of meteors entering the earth's atmosphere. The E_s layer can exist during both day and night, but its presence during the day is difficult to detect because of the presence of the normal E layer. The distribution of this layer cannot be predicted, but it is known to vary on thickness and ion density and is frequently patchy. It is also known that the likelihood of the existence of a sporadic E layer increases with distance from the equator. The layer's occurrence is frequent enough in the middle latitudes to render E_s sky-wave propagation from 25 to 50 percent of the time at frequencies up to 15MHz. It is notorious for causing strong interference between upper hf and lower vhf at great distances, beyond the normal service range at these frequencies.

e. Noise.

(1) A satisfactory communication system exists only when the received signal level is sufficient to override the noise level at the output of the receiving system. This implies that there is a minimum required field intensity for satisfactory communication. This minimum required field intensity depends upon the receiving antenna, the receiver bandwidth, the quality of the service required, the type of modulation, the noise produced within the receiver, and the level of noise at the receiving location. The noise that must be overcome by the field intensity is random noise and impulse noise, and comes from the atmosphere and the receiver. Random noise may be generated from distant thunderstorms, resistive components and tubes in the receiver, and cosmic noise of interstellar space. (Cosmic noise is seldom a problem for communication below 30MHz.) Although radom noise is irregular, its average level can be measured, and it exhibits a characteristic average power distribution that is constant over the frequency spectrum. Impulse noise may be generated by vehicular ignition systems and local thunderstorms, and it is characterized by discrete, well-separated noise pulses having certain phase relationships.

(2) Atmospheric noise is attributed to world-wide effects of thunderstorm activity. Atmospheric noise is highest in the equatorial regions, where thunderstorms are most frequent, and varies seasonally at the higher latitudes, being highest in the summer months. Atmospheric noise is also higher over land than over sea, because thunderstorms are more frequent over land. Thunderstorm activity occurs with hourly and daily variations, being more frequent between 1200 and 1700 local time, which produces diurnal (daily) atmospheric noise conditions. Storms distant from the receiving station produce random noise, while local storms produce impulse noise. Prediction of the impulse noise from local storms is not feasible, but prediction of the random noise from distant storms is feasible. The ITSA publishes world noise-distribution charts from which can be obtained the noise grade for any receiving site. Minimum required incident field intensity curves for overcoming atmospheric noise are also provided. By using the curve for the proper noise grade, proper season, and proper local time, the field intensity required to overcome atmospheric noise can be determined.

f. Fading.

(1) Another disturbance impairing transmission over hf ionospheric paths is fading. The received signal appears to lose or gain signal strength at times slowly and at times so fast the effect is named flutter. Fading is a phenomenon that can be classified into two basic types: single-path fading and multipath fading. The causes are quite different. In single-path fading, the geometry of the ionospheric path is altered so that the skywave that was once aimed directly at the receiving location now skips over. This kind of fading alters only the signal strength, not the relative phase of the signal components, so that there is no distortion. Multipath fading presents a greater problem. This type of fading is caused by the skywave taking more than one path to reach the receiving location. One path may propagate as a one-hop path; simultaneously, or nearly so, another path may develop as a multihop path, adding relative time delay to the signal. This results in partial and sometimes full cancellation of the signal. Because signal elements (bits) can be affected in relative phase, considerable signal distortion can result. In data or rtty transmission, such distortion will often cause errors in message traffic. In voice transmissions, a reduced speech intelligibility results.

(2) Fading is combatted by the use of one or more techniques, the most common being the spacing of two or more receiving antennas a number of wavelengths apart. Each antenna is connected to a separate, identical receiver. The detected receiver outputs in a system are combined, or "selected" in another system, and the resultant steady output is demodulated by the usual terminal or mux equipment associated with the circuit. Some diversity systems use signal polarization diversity; however, polarization diversity is usually limited to the over-300MHz spectrum where antenna sizes are much smaller. Error detecting and correcting equipment, such as ARQ (automatic repeat request), helps overcome the distortion effect on data or rtty traffic.

57. RELIABILITY OF HF CIRCUITS.

a. High-frequency PTP circuits are not rated in coverage. The hf circuits are designed to produce a minimum error rate in a model mux channel for a specified signal-plus-noise to noise ratio at the receiver demodulator or combiner output. These requirements are not easy to evaluate in the field, unless special test equipment is available or unless the circuit uses digital error-detecting and -correcting equipment. The error-detecting equipment must also be equipped to count character repeats over time. Even so, a high error count may not necessarily indicate equipment trouble. A number of variables affect hf propagation efficiency–over a short interval or over several days. A perfectly well-designed circuit with normally operating equipment may exhibit a higher than normal error rate. Because error-rate criteria are more a matter of basic design and engineering than channel deterioration or maintenance, this order does not include specific test for, or theory of, digital error-rate probabilities. The hf equipment periodic maintenance and equipment performance parameters included in this and other orders are sufficient to preclude loss of service due to deterioration of transmitters, receivers, or antenna systems.

b. Within the limit of the radio horizon, hf broadcast reliability is similar to that of vhf and uhf a-g circuits. Beyond that limit, the line-of-sight ionospheric and tropospheric propagation factors enter, and reliability is more like that of PTP circuits. However, no information is provided in this order for such calculations.

58.-59. RESERVED.

Section 3. VHF AND UHF EQUIPMENT DESCRIPTION

60. GENERAL.

This section contains brief descriptions of typical vhf/uhf transmitters, receivers, transceivers, coaxial transmission lines, antennas, associated ancillary equipment, and wave propagation. For a fulleer description and all equipment theory, consult the applicable equipment instruction books and manuals.

61.-62. RESERVED.

Subsection 1. RF EQUIPMENT

63. ITT MODELS AN/GRT-21 (VHF) AND AN/GRT-22 (UHF) TRANSMITTERS.

The vhf and uhf transmitters are intended for a-g am voice telephoney (A3). The vhf transmitter operates in the 116.00MHz-to-149.975MHz spectrum utilizing one of 1,360 channels spaced 25kHz apart. The uhf transmitter operates in the 225.00MHz-to-399.975MHz spectrum utilizing one of 7,000 channels spaced 25kHz apart. The transmitter (the exciter) contains circuitry that provides a 10W minimum, 90-percent modulated signal output. When not in the dc power mode of operation, the exciter power supply furnishes a charging current to external batteries. Figure 2-32 is the functional block diagram of the transmitters. Described below are the major subassemblies of these transmitters.

a. Oscillator-Multiplier, A8(M). A new oscillator-multiplier, part number (pn) 8009546G1 has replaced the original temperature-controlled crystal oscillator, pn 8004290G1/G2. With the oscillator-multiplier module, the operating frequency can be maintained to a much tighter tolerance. Also, adjustments can be made for crystal aging.

b. Oscillator-Synthesizer, A8(S). The optional oscillator-synthesizer module can replace the crystal-controlled oscillator module to generate a selectable stable frequency when the desired frequency crystal is not available or is inoperable. This module provides for direct dialing of the doubler or quadrupler input frequency. Thumb-wheel switches, accessible behind the front access panel, are used to select the desired channel frequency.

c. Doubler or Quadrupler, A9. In the doubler or quadrupler circuit the crystal oscillator or oscillator-synthesizer output is frequency doubled or quadrupled to the output operating frequency and is voltage-level controlled before amplification by the driver and/or power amplifier.

d. Driver, A10A.1. The driver in the driver-power stage is a three-stage (for uhf) amplifier with the first stage (for vhf) or first two stages (for uhf) amplitude-modulated. The last two of three stages are linear amplifiers. The input of the vhf driver is from the doubler, and its output is a signal to the tunable filter. The uhf driver's input is from the quadrupler;

64. WULFSBERG MODEL WT-100 (VHF) TRANSMITTERS.

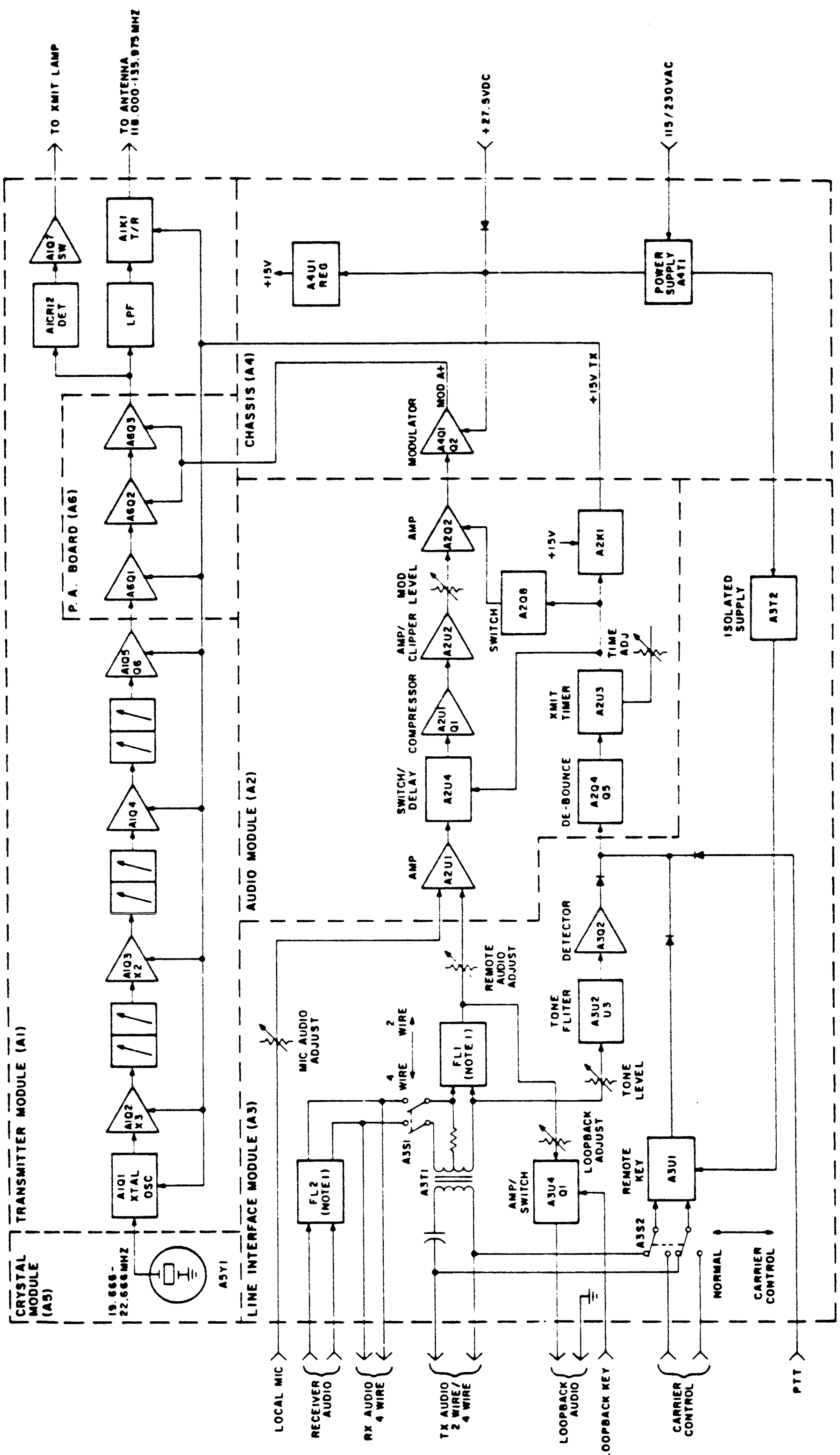
The transmitter is a compact transmitter utilizing 6A3 voice and 13A9 data modulation means on any frequency in the band of 118.00MHz to 135.975MHz. The transmitter is a fixed, single-channel type, with the frequency determined by a plug-in crystal element operating at one-sixth the output frequency. High frequency stability is achieved by the use of a crystal oven. The transmitter is particularly useful where data is to be transmitted over the usual voice bandwidth. An electronic transmit timer is incorporated to limit transmitter ON time should a key-down fault occur in the keying line. (This transmitter timeout may be defeated by incorporation of contractor's engineering order 1026 to allow operation in applications such as ATIS.) The transmitter consists of three basic modules. These three modules are: transmitter module (A1), audio card (A2), and line interface card (A3). These modules plug into the chassis assembly (A4), which contains all the necessary interconnect wiring and cables, as well as a voltage regulator that supplies +15V dc for the transmitter. Figure 2-34 is the functional block diagram of the transmitter. Described below are the major subassemblies of this transmitter.

a. **Transmitter Module, A-1.** The transmitter module (A1) generates and amplifies the rf signal up to the output level, not to exceed 20 watts. The frequency multipliers and filters following the crystal oscillator amplify the signal up to a level suitable for driving the pa board (A6). Modulation and final amplification takes place on the pa board. The transmitter module also contains a six-section elliptical low-pass filter for harmonic energy rejection and an antenna relay to switch the antenna from the receiver to the transmitter when in transmit mode.

b. **Audio Card, A2.** The audio card (A2) contains the transmit audio speech processing circuitry. The transmitter audio input is amplified, filtered, and limited before being applied to the modulator circuitry. A transmit timer and relay on this board supply +15V dc to the transmitter module and also limit transmitter ON time if a key-down fault should occur.

c. **Line Interface Card, A3.** The line interface card (A3) provides the audio input/output signal paths necessary for remote or local operation of the transmitter. This board contains a hybrid transformer which allows both transmit audio input and receiver audio output (when the WT-100 is collocated with a WR-100 receiver) to be passed along a single twisted pair telephone line. Also, keying of the transmitter is controlled by this module. The presence of a tone or a dc current on various input lines will be detected by circuitry on this board and will cause the transmitter to key. Remote transmitter audio and keying can be configured in one of four ways through switching and interfacing on this card. Isolation power for the keying lines is supplied by A3T2 and its associated rectifier/filter. Keying line isolation is maintained by using optoisolator A3U1 to detect a key-down current.

d. **Loopback Audio.** When LOOPBACK KEY line is grounded, A3Q1 turns off, which closes field-effect transistor (FET) switch A3U4. In this mode, the telephone line transmit audio at A4P1 is connected to the LOOPBACK AUDIO lines at A4J1 through LOOPBACK AUDIO LEVEL potentiometer A3R2. This control acts as an adjustable attenuator.



NOTES:
1. THESE FILTERS NECESSARY FOR REJECTION OF KEYING TONE.

Figure 2-34. Block Diagram of the WT-100 (VHF) Transmitter

65. ITT MODELS AN/GRR-23 (VHF) AND AN/GRR-24 (UHF) RECEIVERS.

The vhf and uhf receivers are identical except for their frequency determining elements. The vhf and uhf receivers are single-conversion, crystal-controlled, superheterodyne receivers for am (A3) service. They are identical in physical configuration but differ electrically in the antenna coupler, the tunable filter, and the mixer-multiplier modules. In addition to these modules, the receivers have in common a local oscillator, buffer amplifier, crystal filter, if amplifier and detector, preamplifier with automatic gain control (agc) and squelch circuits, audio amplifier, and power supply. Figure 2-35 is a simplified block diagram of the vhf and uhf receivers.

a. **Antenna Coupler, A7.** The antenna input is fed to the antenna coupler, which provides the capability of operating two receivers from a single antenna. It is an impedance transforming device that allows two receivers to operate from the same antenna with a maximum 2.5dB reduction in sensitivity when receivers are separated by 1.0MHz (vhf) and 3.0MHz (uhf) in operating frequencies.

b. **Tunable Filter, FL2.** The tunable filter provides two tuned cavity sections for preselection of the operating frequency.

c. **Crystal Oscillator, A1.** The 8009546 unit uses a fundamental frequency crystal operating in an oscillator-multiplier circuit; temperature control is not necessary to achieve the required frequency stability.

d. **Mixer-Multiplier, A2.** The mixer-multiplier stages double (vhf) or quadruple (uhf) the oscillator frequency and heterodynes the resultant signal with the received signal to produce a 20.6MHz intermediate frequency.

e. **Buffer Amplifier (or Noise Silencer), A5.** The buffer amplifier isolates the crystal filter from the mixer-multiplier. The center frequency is 20.6MHz, bandwidth 4MHz, or unity gain. Some systems use an interchangeable noise limiter for the buffer amplifier.

f. **Crystal Filter, FL1.** The signal from the buffer amplifier is fed to a 20.6MHz crystal filter, which establishes the receiver selectivity at 50kHz or 25kHz.

g. **IF Amplifier and Detector, A6.** The if amplifier provides a minimum of 94dB of amplification. This signal is then modulated to provide an audio output.

h. **Preamplifier, AF/AGC Squelch, A3.** The detected il (audio) signal is amplified by the preamplifier, and the audio output terminates at two audio volume controls. The agc is obtained by sampling the detected carrier level voltage, amplifying it, and applying this voltage to the mixer-multiplier and if amplifiers. The agc voltage is also fed to the squelch stage to quite the receiver in the absence of a received signal.

i. **Audio Amplifier, A4.** The audio amplifier has two channels, each having 90mW output, one to the phone jack and the other for remote speaker operations.

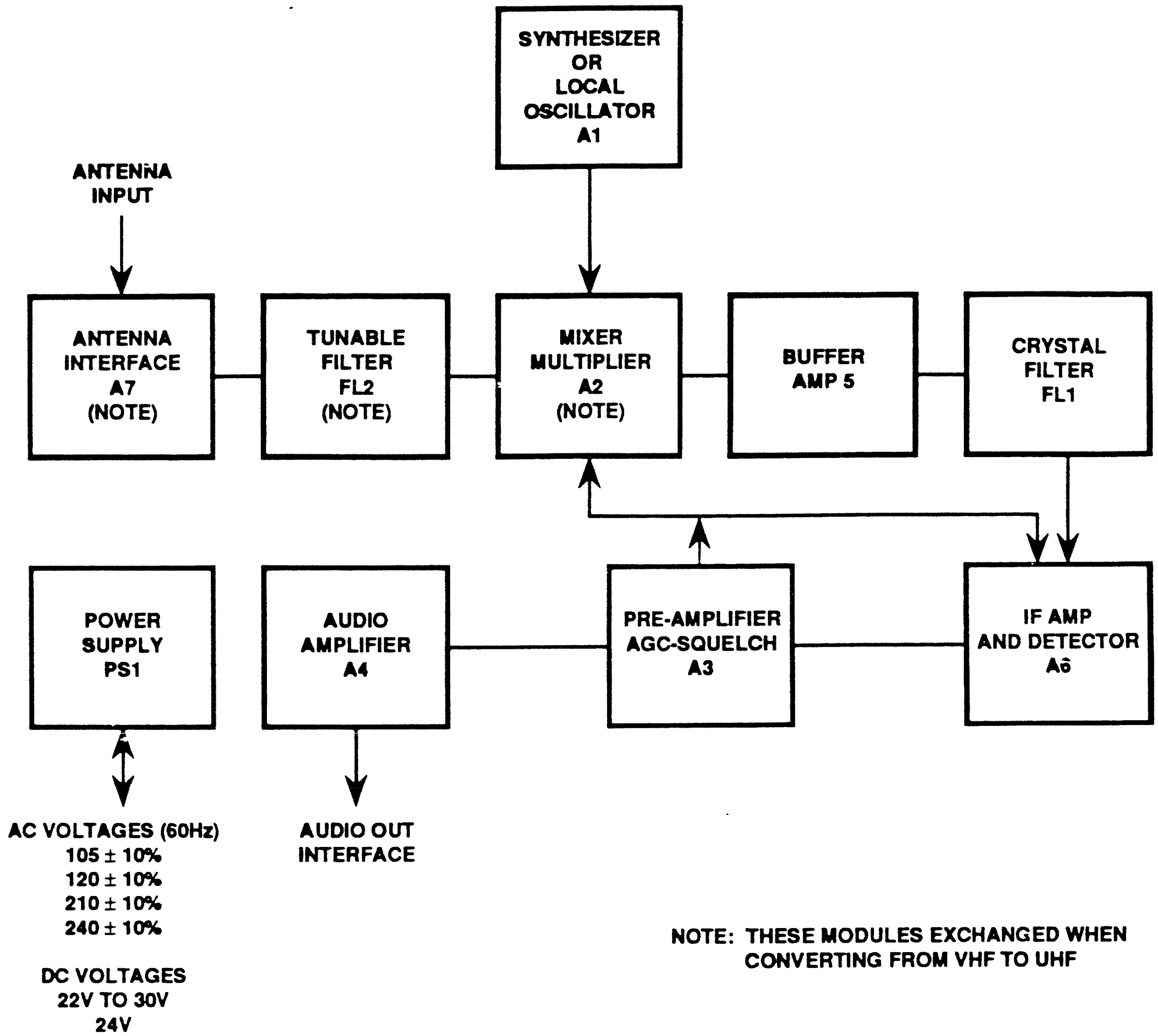
j. **Power Supply, PS1.** The receiver power supply converts the 47Hz to 420Hz ac primary power into regulated and unregulated dc voltage to operate the receiver circuits. When the ac primary input is interrupted, automatic switchover is accomplished to dc input from an external 24V storage battery, if such a battery is used. (These batteries are not supplied at FAA sites, except low-activity ATCT's that use batteries as primary power.)

k. **Oscillator-Synthesizer.** The oscillator-synthesizer is a substitute for any version of the crystal-controlled oscillator or the oscillator-multiplier, when a channel frequency crystal is not available or is not operable. Thumb-wheel switches accessible behind the front access panel are used to select the desired channel frequency.

66. WULFSBERG MODEL WR-100 (VHF) RECEIVER.

The receiver can monitor am (A3) service on any single, fixed frequency in the band of 118.000MHz to 135.975MHz. The unit is a superheterodyne dual-conversion receiver, with the frequency determined by a plug-in crystal element running at one-ninth the first local oscillator frequency. High frequency stability is achieved by use of a crystal oven. The receiver has exceptional selectivity provided by a four-pole helical resonator preselector. As a result, the receiver may operate in close proximity to rf transmitters. Audio output is via either a 600-ohm balanced telephone line or a local speaker. Figure 2-36 is the functional block diagram of the receiver. The receiver consists of three basic modules: if and audio board (A1), receiver module-rf section (A2), and preselector (A3). These modules plug into the chassis assembly (A4), which contains all the necessary interconnect wiring and cables, as well as a voltage regulator that supplies +15V dc for the receiver. Described below are the major subassemblies of the receiver.

a. **IF and Audio Board, A1.** The if and audio board (A1) contains the detection and audio processing circuitry. The post-detection audio is filtered and noise-limited before pass-



* Figure 2-35. Block Diagram of the AN/GRR-23 (VHF) and AN/GRR-24 (UHF) Receivers

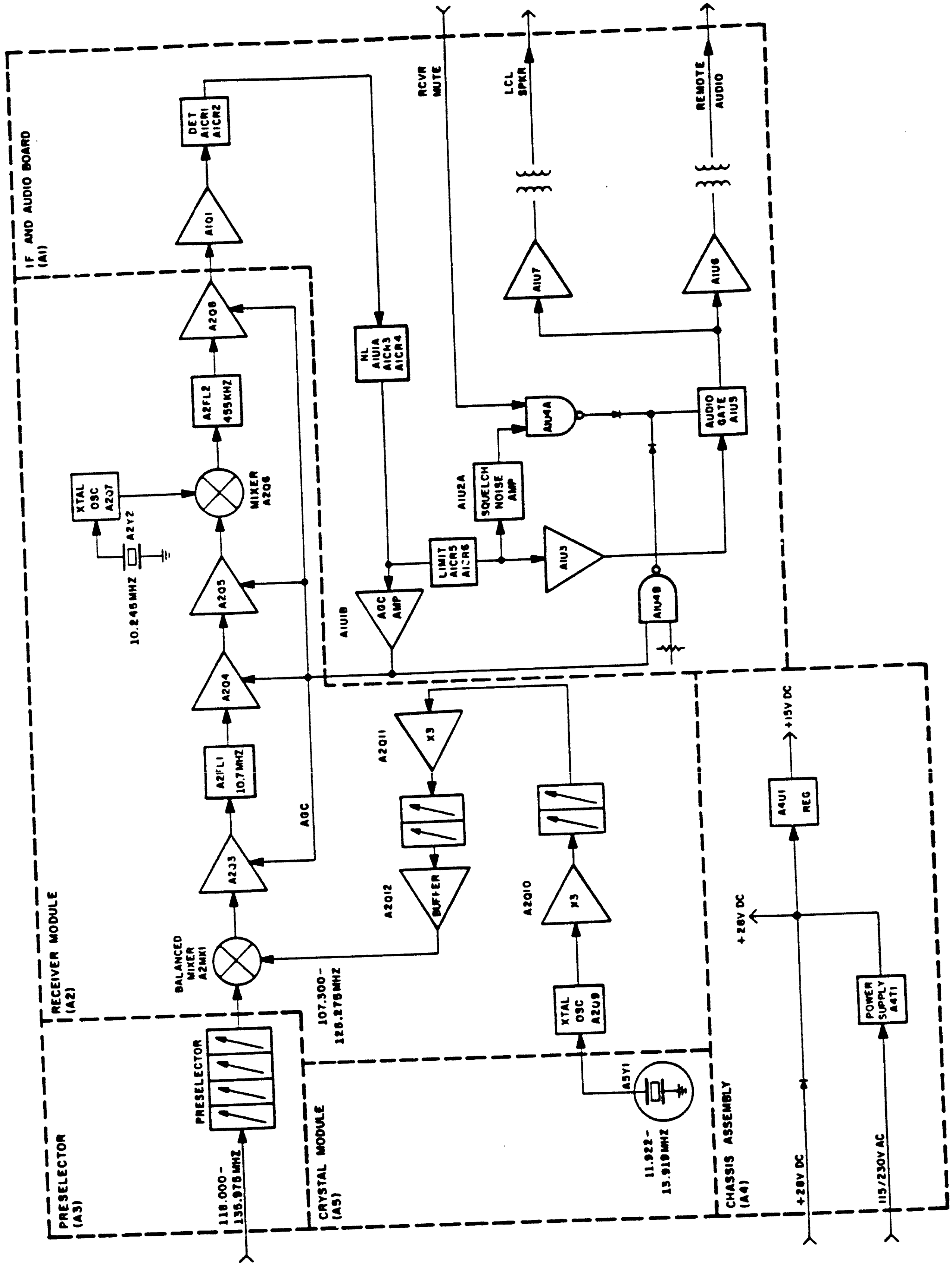


Figure 2-36. Block Diagram of WR-100 (VHF) Receiver

ing to the final audio amplifiers. Noise above the normal audio frequency range is filtered off, rectified, and use to ddrive the signal-to-noise squelch circuitry. This board also contains an agc amplifier which controls the gain of the various if stages and drives the carrier level squelch circuitry.

b. Receiver Module-RF Section, A2. The receiver module-rf section (A2) contains the circuitry which converts the rf signal down to the if frequencies and amplifies it to a level suitable for detection. The receiver is a dual-conversion superheterodyne type utilizing intermediate frequencies of 10.7MHz and 455kHz. The receiver frequency is controlled by a plug-in crystal module (A5) which sets the frequency of the first local oscillator. Multipliers, filters, and buffers amplify the local oscillator output up to a level suitable for injection into the first mixer. The 10.7MHz output of the mixer is amplified, filtered, and mixed with a second local oscillator to produce a pre-detector if signal at 455kHz.

c. Preselector, A3. The preselector bandpass filters the incoming rf signal. The preselector is a four-pole helical resonator type that provides a high level rejection of image and spurious signals with a minimum of insertion loss. The filter consists of four helical coils resonated by tuning capacitors. Once tuned properly, the preselector can achieve skirt rejection in excess of 100dB at the image frequency, with less than 5dB passband attenuation.

d. Signal-to-Noise Squelch. The signal-to-noise squelch circuit operates on the principle that the noise component of the audio output from the am detector decreases, or quiets, as the rf signal input is increased. This reduction in noise (i.e., increase in the signal-to-noise ratio) can be detected and used to operate the squelch gate circuitry. An 8kHz high-pass filter whose gain is controlled by s/n squelch adjust potentiometer strips off any voice-band audio and passes only those frequency components (presumably noise) which lie above the normal voice passband. The noise output is rectified and filtered, producing a voltage which is proportional to the noise signal.

*** 67. MOTOROLA MODELS CM-200VT (VHF) AND CM-200UT (UHF) TRANSMITTERS.**

The very high frequency (vhf) and ultra high frequency (uhf) transmitters are identical except for their frequency * determining elements. The vhf and uhf transmitters use a microprocessor to control and display all tuning and monitored functions. The technician interfaces with the microprocessor via four push-button menu control/programming switches and a liquid crystal display (LCD). The push-button switches and LCD display may be used to select the operating frequency and make operational parameter adjustments to the transmitter. Various transmitter functions such as relative transmitted signal strength and internal power supply voltage levels may also be monitored via the LCD display. Figure 2-36.1 depicts a simplified block level diagram of the vhf and uhf transmitters.

a. Front Panel Controls and Indicators. The front panel controls and indicators consist of ac and dc power circuit breakers and light emitting diodes (LED), four push-button menu control/programming switches, vswr and transmit LED's, an LCD, and a microphone push-to-talk (PTT) jack.

b. Microprocessor. In normal operation, the microprocessor continuously runs an operational program to digitally control and monitor all parameters of the transmitter. Selected values for critical performance parameters may be input to the microprocessor via the front panel adjustments and push-button switches.

c. RF Synthesizer. The radio frequency (rf) synthesizer maintains the transmitter output frequency via a voltage controlled oscillator (vco), a phase lock loop (PLL), and control signals from the microprocessor. The frequency output range is 117.975 MHz to 136.975 MHz for vhf transmitters and 225 MHz to 399.975 MHz for uhf transmitters adjustable in 25 kHz steps.

d. Voltage Controlled Attenuator/Amplifier. The voltage controlled attenuator/amplifier utilizes a PIN diode attenuator and a voltage controlled amplifier to regulate the signal level driving the rf power amplifier and to provide audio frequency amplitude modulation. The voltage controlling the attenuator/amplifier is supplied from the automatic level control (alc) section. *

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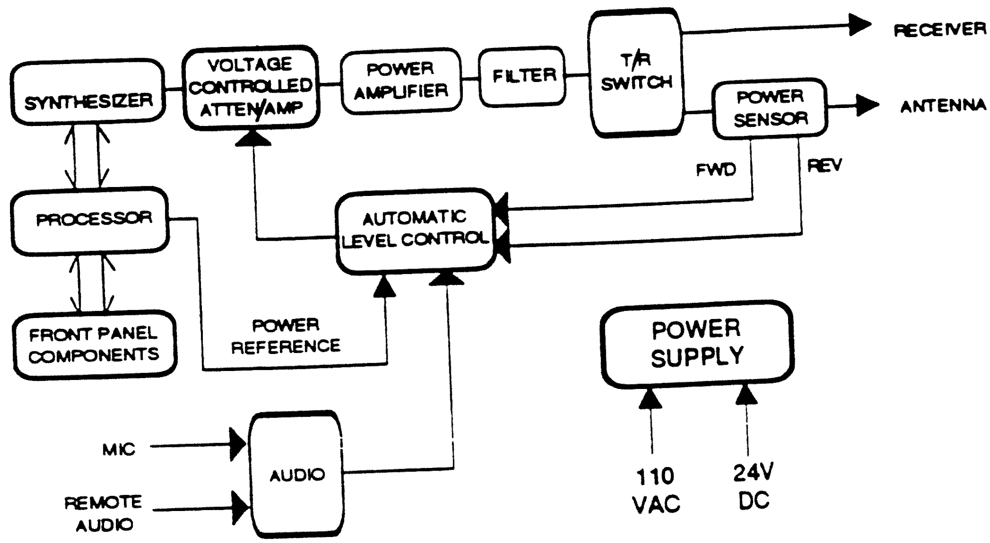

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Figure 2-36.1. Block Diagram of CM-200VT and CM200-UT

* e. **RF Power Amplifier.** The power amplifier (pa) is a two stage, fixed gain, rf amplifier, which is designed to deliver ten watts of continuous rf power. By means of the internal microprocessor and circuitry, the transmitter pa temperature and vswr are constantly monitored. If the microprocessor detects an abnormally high pa temperature or vswr, it will instantly reduce the pa output power to protect it from the over-temperature or high vswr condition.

f. **RF Filter.** The rf filter is a seven-pole bandpass filter, which passes output signals within the intended bandwidth of the particular transmitter. Signals outside of the passband of the rf filter are rejected. The bandwidth of the transmitters are: 117.975 MHz to 136.975 MHz for vhf transmitters, and 225 MHz to 399.975 MHz for uhf transmitters.

g. **RF Transmit/Receive Switch.** The rf transmit/receive (t/r) switch consists of diodes which pass signals from the antenna to the receiver when the transmitter is idle. Signals are blocked from the transmitter to the receiver when the transmitter is active. This configuration allows a transmitter/receiver pair to operate in a transceiver mode. *

* h. **RF Power Sensor.** The rf power sensor utilizes an rf coupler and diodes to produce two dc voltages that are representative of the transmitter forward and reverse power. These voltages are utilized by the automatic level control and vswr protection circuitry of the transmitter.

i. **Automatic Level Control (ALC).** The alc section receives representative voltages of forward and reverse power, control voltages from the microprocessor (for setting the modulation level and rf output power), and a audio signal level from the audio section. The output voltage from the alc establishes the rf power output of the transmitter and maintains a constant amplitude modulation for varying levels of audio input.

j. **Audio Frequency (AF) Section.** The af section of the transmitter amplifies the audio signal from the microphone input and/or the remote input. The audio section contains an automatic gain circuit and audio bandpass filter with a frequency range of 300 to 3400 hertz. *

* **k. Power Supply.** The transmitter power supply utilizes switching circuitry to convert primary power (120 Vac or 20 to 30 Vdc) to the operating voltages used internally to the transmitter. These voltages are: +5 Vdc, +12 Vdc, -12 Vdc, and +80 Vdc.

68. MOTOROLA MODELS CM-200VR (VHF) AND CM-200UR (UHF) RECEIVERS.

The very high frequency (vhf) and ultra high frequency (uhf) receivers are identical except for their frequency determining elements. The vhf and uhf receivers use a microprocessor to control and display all tuning and monitor functions. The technician interfaces with the receiver's microprocessor via four push-button switches and a liquid crystal display (lcd). The push-button switches and lcd display may be used to select the operating frequency and make operational parameter adjustments to the receiver. Various receiver functions such as relative received signal strength and internal power supply voltage levels may also be monitored via the lcd display. Figure 2-36.2 dipicts a simplified block diagram of the vhf and uhf receivers.

a. Pre-selector. Signals from the antenna are applied to the pre-selector section which provides tuned bandpass filtering to select the desired frequency and reject all others. The tunable range of the filters is 117.975 MHz to 136.975 MHz for the vhf receiver and 225 MHz to 399.975 MHz for the uhf receiver. The received signal is amplified by a low noise amplifier (LNA) and converted to the 45 MHz intermediate frequency (if) by mixing it with the local oscillator (lo) frequency supplied by the synthesizer. The synthesizer frequency has been set by the processor to the operating frequency (Fo) + 45 MHz. A variable attenuator at the input of the pre-selector reduces the amplitude of large input signals. The amount of attenuation is a function of the input signal strength and is controlled by the automatic gain control (agc) voltage. This allows the receiver to receive signals as high as 200 mV rms without overdriving the receiver.

b. First IF Stage. The first if stage receives 45 MHz from the pre-selector. This stage provides filtering, amplification, and converts the frequency to the second if frequency of 455 kHz. Filtering is accomplished by two * * crystal filters that provide off-channel rejection and selectivity. The overall gain of this stage is controlled by the agc voltage and the frequency conversion takes place by mixing the first if (45 Mhz) and the output of the second lo synthesizer, which is fixed at 44.545 MHz. The 455 kHz output is applied to the second if stage.

c. Second IF Stage. The second if stage also provides agc controlled amplification. A 455 kHz ceramic filter provides additional selectivity. The output of this stage is applied to the detector.

d. Detector. The detector stage has two basic functions; to strip the am modulation from the if signal and apply it to the audio circuits, and to detect the amplitude of the incoming signal to develop the agc voltage. This agc voltage is then used to control the gain through the rf, if, and audio stages.

e. Audio. The audio circuit provides a constant output level amplifier stage controlled by the agc voltage. The output level is a function of modulation percentage. This stage also provides post-detection filtering to limit the audio output to a bandwidth of 300 Hz to 3.5 kHz. Two separate audio amplifiers drive the two balanced outputs, remote audio out at connector J2 on the back panel, and headset audio out on the front panel. Separate volume controls are provided for each output. The squelch circuit consists of a comparator amplifier that compares the agc voltage to a voltage set by a squelch potentiometer on the front panel. If the agc voltage is lower than the squelch voltage, the audio output is muted.

f. Synthesizer. The synthesizer is phase lock loop (pll) controlled with a frequency range of 162.975 MHz to 181.975 MHz for the vhf receiver and 270 MHz to 444.975 MHz for the uhf receiver, 45 MHz higher than the operating frequency range. Data to select the proper frequency is supplied by the processor based on operator inputs. The frequency can be adjusted in 25 kHz steps.

g. Second LO Synthesizer. The second lo synthesizer is a fixed tuned pll synthesizer that operates at 55.545 MHz. *

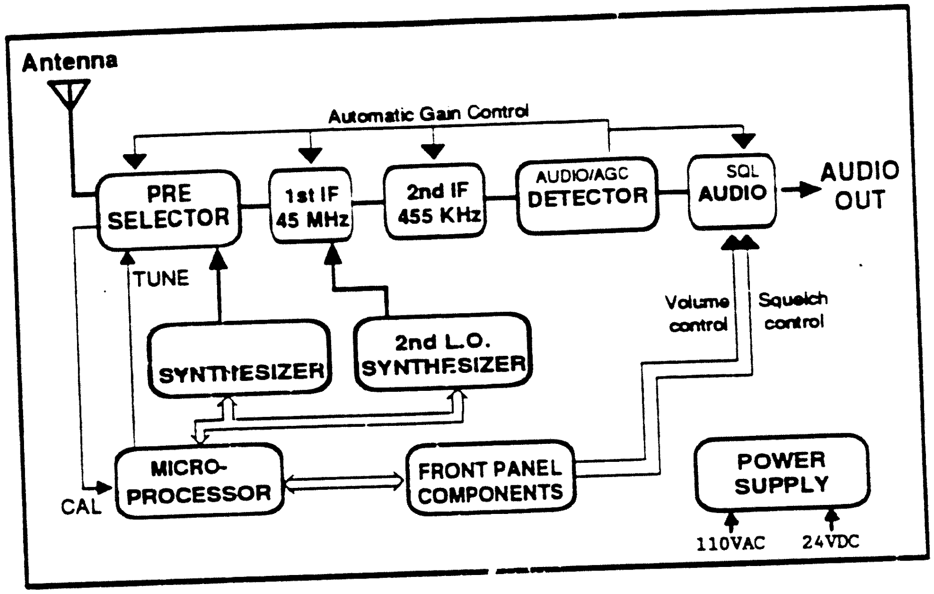


Figure 2-36.2. Receiver Block Diagram

h. Front Panel Components. The front panel components consist of the liquid crystal display (LCD), four control push buttons, and the volume and squelch controls.

i. Microprocessor. In normal operation the microprocessor continuously runs an operational program to digitally control and monitor all parameters of the receiver. Selected values for critical performance parameters may be input to the microprocessor via the front panel adjustments and push-button switches.

j. Power Supply. The receiver power supply utilizes switching circuitry to convert primary power (120 V ac or 20 to 30 V dc) to the operating voltages used internal to the radio. These voltages are: +24 V dc, +12 V dc, −12 V dc, +5 V dc, and −5 V dc.

***69. MOTOROLA MODELS CM-50 (VHF)/CM-51 (UHF) LINEAR POWER AMPLIFIERS (LPA).**

The very high frequency (VHF) and ultra high frequency (UHF) LPA's are virtually identical. Where differences exist, they will be explained in the text and the model number of the applicable unit will be identified. All equipment controls are located on the front panel. They are the ac power switch, the dc power switch, the three-position operating mode switch, and the rf power adjust control. In the operational configuration, the three-position operating mode switch should always be in the NORMAL position. In this mode, the LPA monitors input and output rf levels, and based on these levels, either* *amplifies or bypasses the signal. In the BYPASS switch position, the LPA is in a mode where it does not amplify the rf signal regardless of input level. Finally the TEST position forces the LPA into a mode where it always amplifies the input signal. The BYPASS and TEST switch positions are intended to be used only for bench testing of the LPA's.

The LPA is a solid-state rf amplifier that has several built-in safety and convenience features. The LPA may be powered by 120 V ac, +24 V dc, or both. In the case where both ac and dc power is supplied, the LPA is designed to draw its operating power from the ac line. For the CM-50 VHF LPA, the operating currents range from less than 1 amp in the receive mode to 3.5 amps from the ac line or 10 amps from the dc line in the transmit mode. For the CM-51 UHF LPA, the operating currents range from less than 1 amp in the receive mode to 5 amps from the AC line or 16 amps from the dc line in the transmit mode.

The normal transmit mode is entered when the LPA automatically detects the presence of a transmit signal (8 to 12 watts) at the rf input connector. The LPA switches from the receive mode into the transmit mode, amplifies the signal to a 50-watt rf level and indicates the mode by lighting the 50W TX indicator on the front panel. For the receive mode the LPA connects the signal coming in the antenna (rf output connector) to the rf input connector and the RX indicator is illuminated. *

Subsection 2. TRANSMISSION LINES

70. GENERAL.

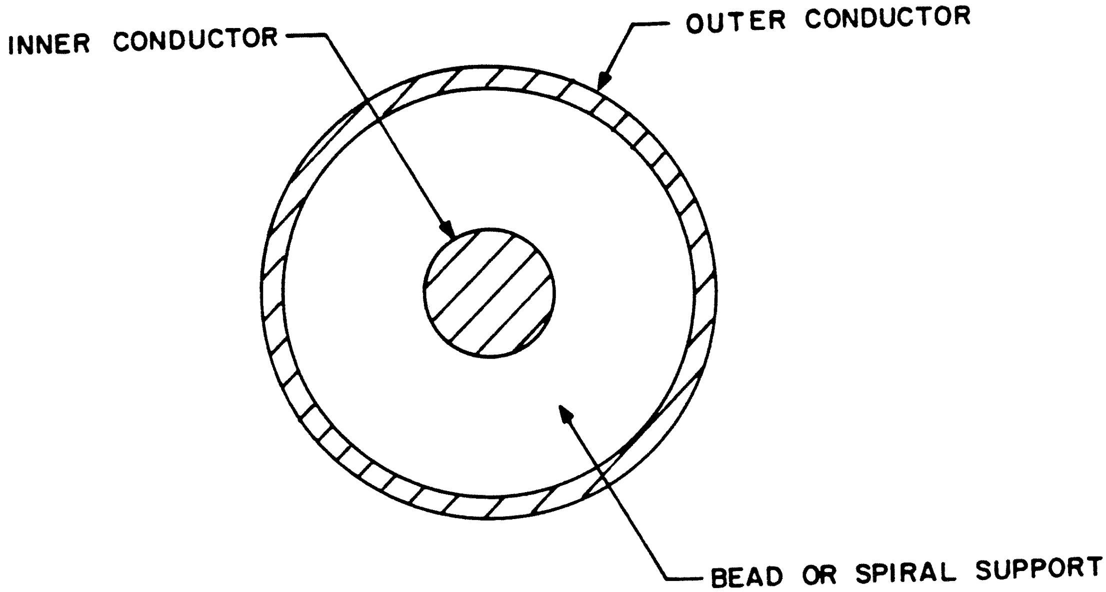
For frequencies over 30MHz, the common type of transmission line is the concentric line called coaxial cable. This cable is available in a wide variety. Figure 2-37 illustrates two types of coaxial cable transmission lines, the air dielectric and the solid dielectric coacial cable. The inner conductor may be either solid or standard wire. Insulating material between the inner and outer conductors may be air (shown in part A) or some material such as polyethylene or foam (shown in part B). The outer conductor is either braid or tubing. The coaxial line is used in the agency for feeding antennas used at vhf and uhf frequencies.

71. COMBINERS AND MULTICOUPLERS.

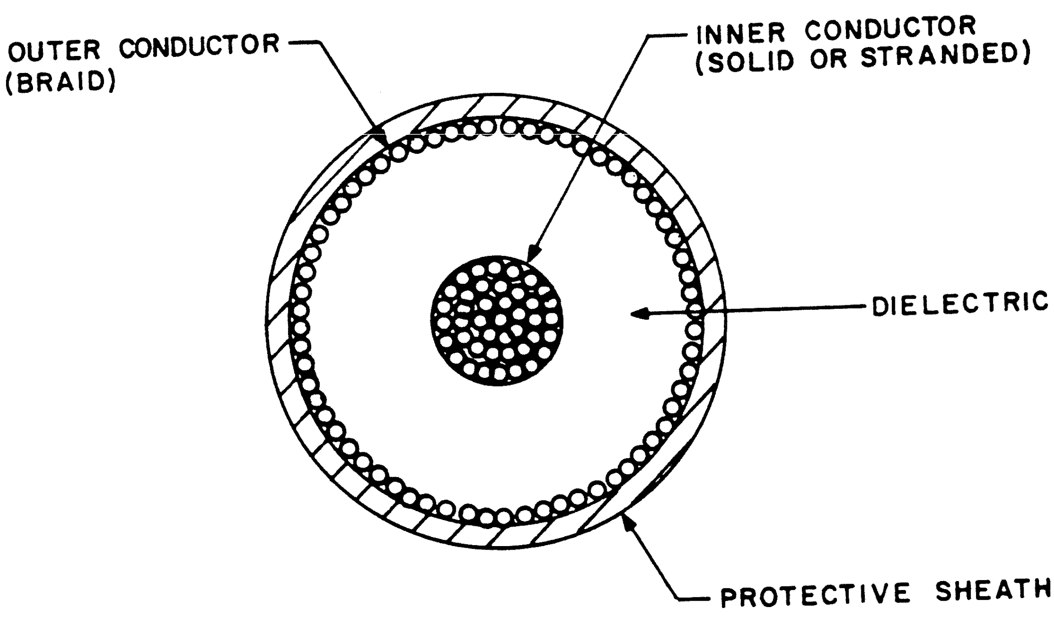
The terms combiners and multicouplers are sometimes used interchangeably. However, combiners are normally associated transmitters and multicouplers with receivers. They are both devices designed to allow the connection of several transmitters or receivers to one antenna.

a. Combiners are tuned-cavity devices which allow more than one transmitter to share a single antenna. They employ one or more cavities tuned to the associated transmitter frequency, and as such provide isolation between units and suppression of spurious and harmonic emissions. Additionally, the passive design of these units make them virtually fail proof. A disadvantage is they introduce a signal loss.

b. Multicouplers may be either passive or active. Passive multicouplers consist of tuned cavities. They provide isolation between receivers and rejection to off-frequency signals. They are virtually fail proof; however, they have an insertion loss causing a decrease in signal level. Active multicouplers, used only with receivers, provide signal amplificaiton that can more than offset insertion loss. Although they can combine a large number or receivers, up to twelve, in normal practice they are limited to four receivers to minimize the impact of loss of antenna, coaxial cable, or multicoupler. The broadband nature of the input circuits required for full band coverage is a distinct disadvantage. Also,strong signals may cause nonlinear operation and result in intermodulation distortion. The active elements are subject to failure, which may result in loss of service.



A. AIR DIELECTRIC



B. SOLID DIELECTRIC

Figure 2-37. Coaxial Cable Transmission Lines

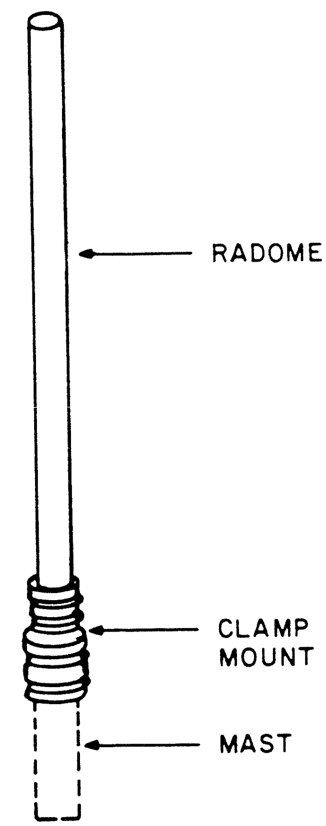
Subsection 3. ANTENNAS

72. GENERAL.

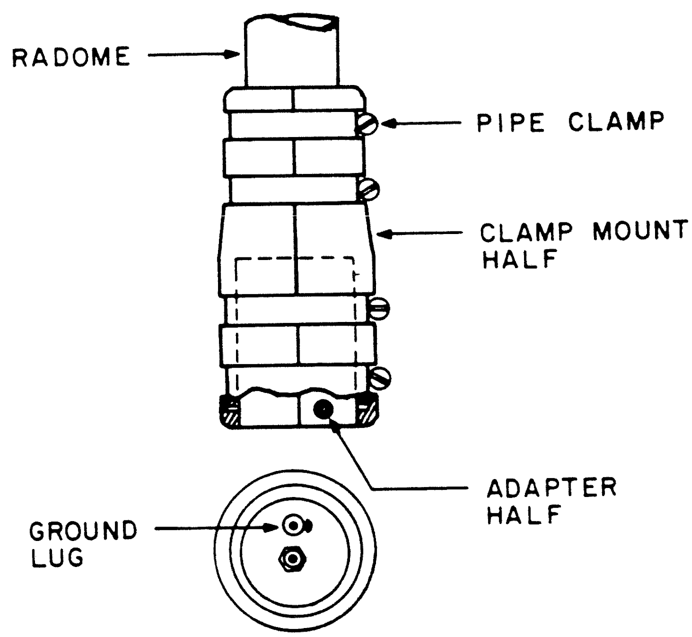
The general type of ground-based vhf/uhf air-ground radio communication antenna is the collinear, vertically polarized, omnidirectional dipole antenna. The simplest antenna is a single input antenna that has no gain over a reference dipole antenna. There are multiple input antennas with no gain, and single input antennas with gain. The radiation patterns in the horizontal plain are usually circular with a minimum of distortion. Additionally, there is limited application of directional gain antenna, such as a Yagi array and a log periodic. A brief description of the types most often used at agency facilities is contained in the following paragraphs.

73. VHF SINGLE INPUT ANTENNAS.

a. The TACO model D-2276 is a single-element, vertically polarized omnidirectional antenna, specifically designed to provide optimum performance throughout the frequency band of 118 to 136 MHz. The radiating element is enclosed in a completely sealed 1.50-inch (3.81cm) diameter fiberglass radome. Figure 2-38, part A, is a general illustration of the antenna. Part B of the figure is a detail of the mounting clamp supplied with each antenna. An optional clamping arrangement permits mounting on either a 1.25-inch (3.175cm) or a 2.50-inch (6.35cm) mast. The clamp provides in-line mounting with the mast, which allows feeding the antenna without



A. ANTENNA ASSEMBLY



B. MOUNTING CLAMP DETAIL

Figure 2-38. General View of TACO Antenna exposing the transmission line. The antenna and clamp combination meets windload requirements of 85 knots with 1/2-inch (1.27cm) radial ice coating.

b. The design employed in the antenna results in broadband half-wave dipole characteristics over 118 to 136 MHz. The desired figure-eight radiation pattern is generally constant throughout the band. Through broadband suppression of extraneous currents upon the transmission line, the undesirable clover leaf pattern is avoided. The outer conductors of both halves of the dipole are at dc ground potential. A grounding lug is provided at the base of each antenna for supplemental grounding capability. Figure 2-39 shows the voltage standing-wave ratio (vswr) and radiation characteristics of the antenna.

c. Antenna Products Corp model DPV-35 is an equivalent of the TACO D-2276.

74. UHF SINGLE INPUT ANTENNAS.

a. The TACO model D-2277 is a single-element, vertically polarized omnidirectional antenna, specifically designed to provide optimum performance throughout the frequency band of 225 to 400 MHz. The radiating element is enclosed in a sealed 1.50-inch (3.81cm) diameter fiberglass radome (see figure 2-38). An optional clamping arrangement permits mounting on a 1.25-inch (3.175cm) or a 2.50-inch (6.35cm) mast. The clamp provides in-line mounting with the mast, which allows feeding the antenna without exposing the transmission line. The antenna and clamp combination meets windload requirements of 85 knots with 1/2-inch (1.27cm) radial ice coatings.

b. The design of the antenna results in broadband half-wave dipole characteristics over 225 to 400 MHz. The desired figure-eight radiation pattern is generally constant throughout the band. Through broadband suppression of extraneous currents upon the transmission line, the undesirable clover leaf pattern is avoided. The outer conductors of both halves of the dipole are at dc ground potential. A grounding lug is provided at the base of each antenna for supplemental grounding capability. Figure 2-39 shows vswr and radiation characteristics of the antenna.

c. Antenna Products Corp model DPV-37 is an equivalent of the TACO D-2277.

75. VHF DUAL INPUT ANTENNAS.

a. The TACO model D-2272 is a dual-element, vertically polarized omnidirectional antenna, specifically designed to provide optimum performance throughout the frequency band of 118 to 136 MHz. The two independently operating elements are enclosed in a sealed 2.250-inch (5.72cm) diameter fiberglass radome (see figure 2-38). An optional clamping arrangement permits mounting to either a 1.25-inch (3.175cm) or a 2.50-inch (6.35cm) mast. The clamp provides in-line mounting with the mast, which allows feeding the antenna without exposing the transmission line.

b. The design of the antenna results in broadband half-wave dipole characteristics over the 118MHz-to-136MHz band. The desired figure-eight radiation pattern is generally constant throughout the band. Through broadband suppression of extraneous currents in the transmission line, the undesirable cloverleaf pattern is avoided. The outer conductors of both halves of each dipole are at dc ground potential. A grounding lug is provided at the base of each antenna for supplemental grounding capability. Figure 2-39 shows vswr and radiation characteristics of the antenna.

c. Antenna Products Corp model DPV-36 is an equivalent of the TACO D-2272.

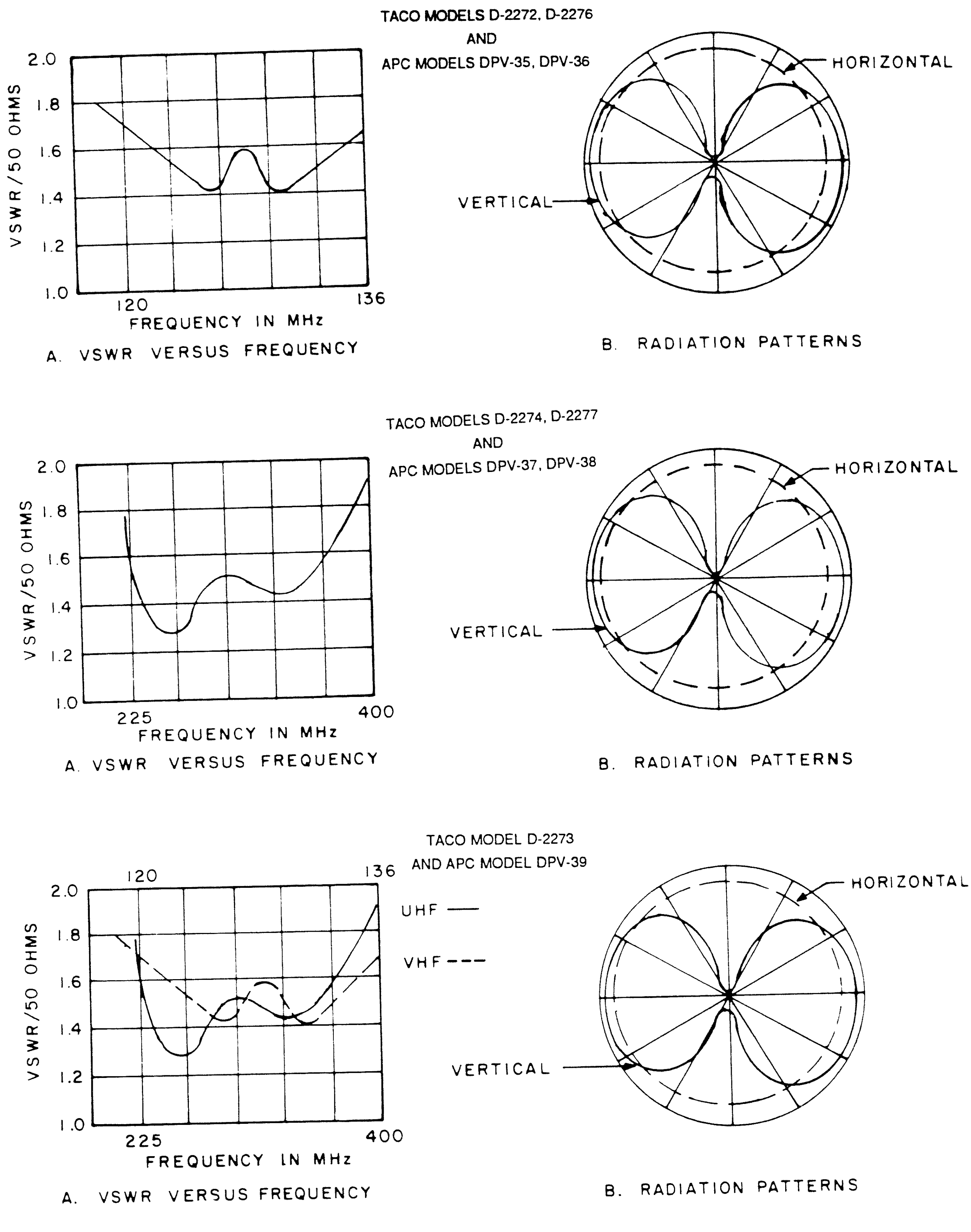


Figure 2-39 VSWR and Radiation Patterns, VHF and UHF Dipole Antennas

76. UHF DUAL INPUT ANTENNAS.

a. The TACO model D-2274 is a dual-element, vertically polarized omnidirectional antenna, specifically designed to provide optimum performance throughout the frequency band of 225 to 400 MHz. The two independently operating elements are enclosed in a sealed 2.250-inch (5.72cm) diameter fiberglass radome (see figure 2-38). An optional clamping arrangement permits mounting on a 1.25-inch (3.175cm) or a 2.50-inch (6.35cm) mast. The clamp provides in-line mounting with the mast, which allows "feeding" to the antenna without exposing the transmission line.

b. The design of the antenna results in broadband half-wave dipole characteristics over the 225 to 400 MHz. The desired figure-eight radiation pattern is generally constant throughout the band. Through broadband suppression of extraneous currents in the transmission line, the undesirable cloverleaf pattern is avoided. The outer conductors of both halves of each dipole are at dc ground potential. A grounding lug is provided at the base of each antenna for supplemental grounding capability. Figure 2-39 shows vswr and radiation characteristics of the antenna.

c. Antenna Products Corp model DPV-38 is an equivalent of the TACO D-2274.

77. VHF/UHF DUAL INPUT ANTENNAS.

a. The TACO model D-2273 is a dual-element, vertically polarized omnidirectional antenna, specifically designed to provide optimum performance throughout the frequency bands of 118 to 136 MHz and 225 to 400 MHz. The two independently operating elements are enclosed in a sealed 2.250-inch (5.72cm) diameter fiberglass radome (see figure 2-38). An optional clamping arrangement permits mounting on a 1.25-inch (3.175cm) or a 2.50-inch (6.35cm) mast. The clamp provides in-line mounting with the mast, which allows feeding the antenna without exposing the transmission line.

b. The design of the antenna results in broadband half-wave dipole characteristics over the 118 to 136 MHz and 225 to 400 MHz. The desired figure-eight radiation pattern is generally constant throughout the band. Through broadband suppression of extraneous currents in the transmission line, the undesirable cloverleaf pattern is avoided. The outer conductors of both halves of each dipole are at dc ground potential. A grounding lug is provided at the base of each antenna for supplemental grounding capability. Figure 2-40 shows the vswr and radiation characteristics of the antenna.

c. Antenna Products Corp model DPV-39 is an equivalent of the TACO D-2273.

78. VHF OMNIDIRECTIONAL GAIN ANTENNAS.

a. The TACO model D-2261A is a multielement, vertically polarized, omnidirectional gain antenna designed to operate across the frequency band of 118 to 136 MHz. It weighs 14 pounds (6.36kg) and is 142 inches (3.6m) long. The antenna elements are sealed inside a 1.5-inch (3.81cm) diameter, filament-wound fiberglass enclosure, which has a molded fiberglass clamp at the base of the antenna for installing the antenna on a 3-inch (7.62cm) diameter support mast. The vertical radiation pattern at 127MHz has a vertical beam width of 40° with an upward tilt. The horizontal radiation pattern has a 1.5dB variation in its omnidirectional pattern. The gain of the antenna is 1.5dB over the standard gain dipole. The gain of the antenna is 4dB over an isotropic antenna.

b. Antenna Products Corp model DPV-40 is an equivalent of the TACO D-2261A.

79. VHF DIRECTIONAL GAIN ANTENNAS.

a. The TACO model Y102-B-130V vhf 10-element, stacked Yagi array antenna is a vertically polarized, directional antenna designed to operate across the frequency band of 118 to 136 MHz. It weighs 12 pounds (5.4kg) and is 103 (2.6m) inches long and 50 inches (1.3m) high. The antennas are vertically stacked 10 feet (3.04m) apart and are connected together with a stacking harness to permit increased gain. The single-antenna, vertical radiation pattern at 136MHz has a vertical beam width of 50°. The single antenna horizontal radiation pattern has a horizontal beamwidth of 62°. The horizontal radiation pattern for two antennas vertically stacked and skewed 0° reduces the horizontal beamwidth from 62° to 54°. The gain of the single Yagi antenna is 12dB over a standard dipole at 136MHz. The antenna gain increases 3dB when stacked and skewed 0°, and decreases 3dB when stacked and skewed 180°. See figure 2-40.

b. There are similar antennas by other manufacturers in the present population of FAA antennas.

80.-81. RESERVED.

82. GROUND-MOBILE AND BASE-STATION ANTENNAS.

Some effective base-station antennas serving ground-mobile operations are shown in figures 2-26 and 2-27. Figure 2-26 shows four omnidirectional types: the ground-plane or folded ground-plane (a modified quarter-wave whip); the turnstile, a type much more effective than the whip; the Franklin, a type permitting gain over a skirted coaxial antenna; and the skirted coaxial type, which behaves as a half-wave dipole in free space. Omnidirectional characteristics may not

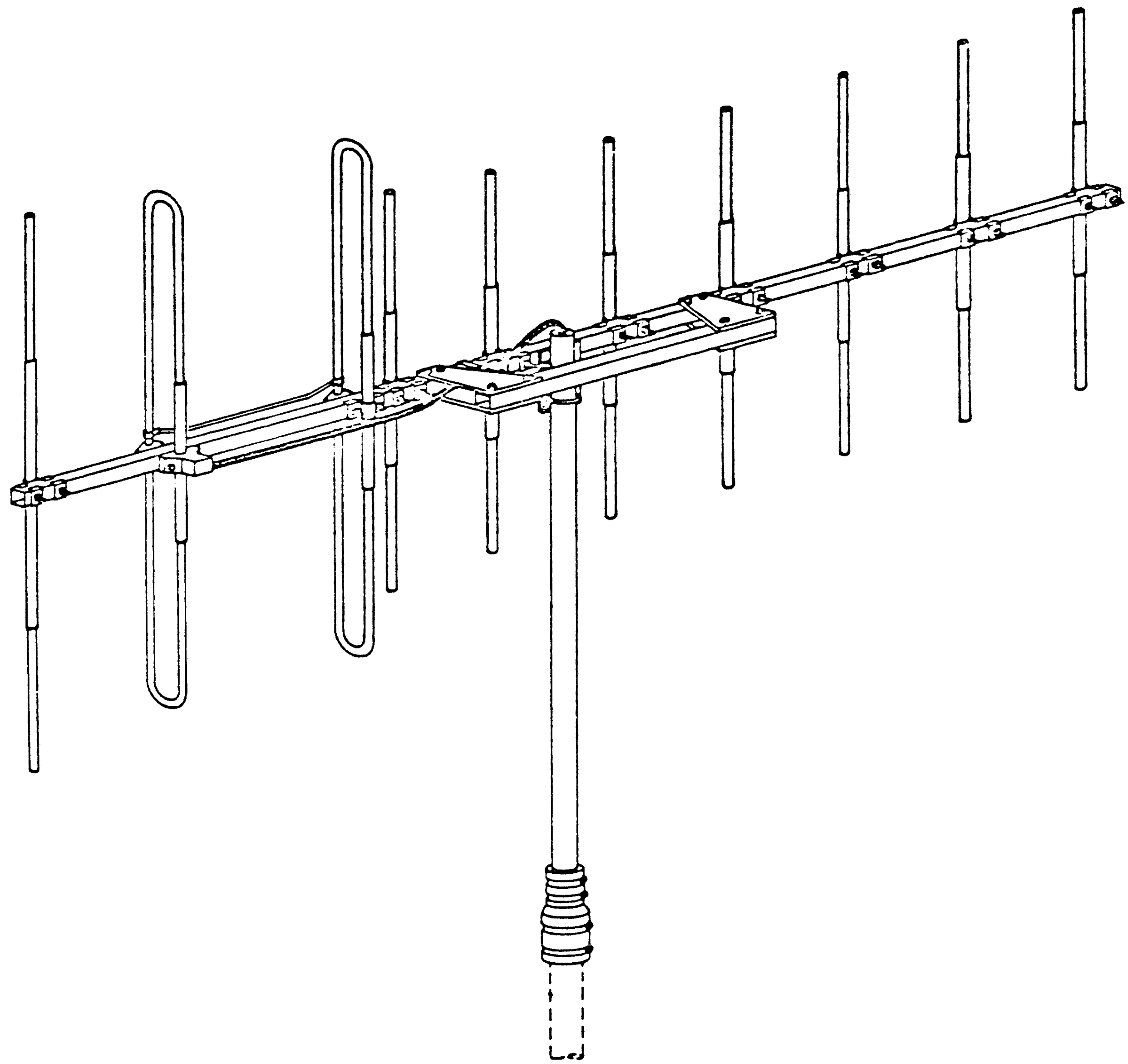


Figure 2-40. TACO Model Y102B-130V VHF Yagi Antenna

always be desirable in base station facilities (as they are on vehicular antennas). Certain directional antennas such as the corner reflector or Yagi are used to focus radiation in selected corridors or areas. Figure 2-27 shows the two frequently used base-station antennas, the corner reflector and the Yagi in stacked form. The vehicular mount can appear as a whip or quarter-wave stub mounted on trunk or roof. The metal surface of the trunk or roof makes an effective, although somewhat distorted in effect, ground plane. Figure 2-28 shows three whips and two stubs.

83. RADIO LINK ANTENNAS.

The antennas used for radio link service are almost exclusively operated over 30MHz and are of high directional gain. Both parasitic arrays (Yagi) (figure 2-27) and corner-reflector antennas are common types, depending on path characteristics and reliability requirements. Figure 2-41 is a corner-reflector antenna with a dipole as a radiating element. These directive link antennas must be oriented precisely horizontal polarization in one antenna and vertical polarization in the other. Connected to different receivers, and the two receiver outputs combined, the fade margin of the link circuit is improved.

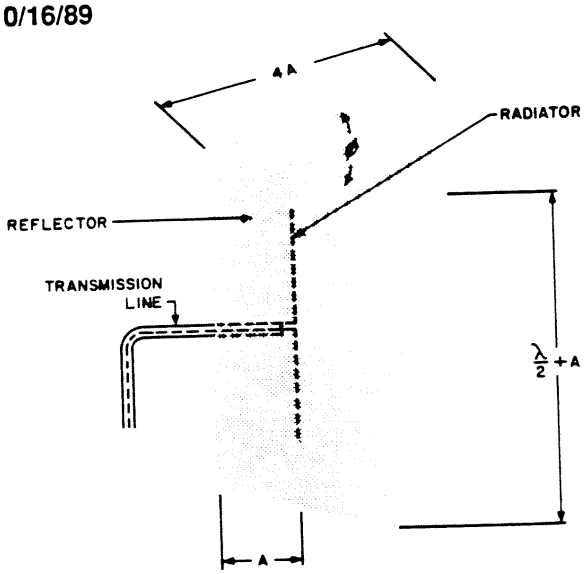


Figure 2-41. Corner-Reflector Antenna for Radio Link

84.-89. RESERVED.

Subsection 4. WAVE PROPAGATION

90. GENERAL.

A brief discussion of radio wave propagation at vhf and uhf frequencies is included in this subsection. The geometry of propagation in the vhf and uhf frequency bands, including certain propagation disturbances having the greatest effect on the reliability of air-ground radio communication, is included.

91. BASIC.

Propagation of vhf and uhf waves differs from that of hf waves principally because the layers of the ionosphere are not required for propagating the signals of higher frequency (over 30MHz). At times, the D and E regions may have an effect on the propagational efficiency of the higher frequency waves. For the most part, the propagation is line of sight and little bending or wave refraction occurs. The line-of-sight mode of propagation can be represented by an imaginary cylinder called the service volume. Examples of the service volume for various air traffic control zones are shown in figure 2-42. The main transmission factors to provide required coverage in the service volume are effective radiated power, antenna pattern or directivity, and transmission loss (attenuation of the signal through the atmosphere). The transmission loss is modified over and above the basic free-space loss by obstructions, absorption of higher frequencies, and ducting. Obstructions may be mountains, hills, trees, tall buildings, and the like. Other derogating factors decreasing communication reliability can be direct-wave cancellation by multipath propagation, co-channel interference, adjacent-channel interference, and atmospheric or man-made noise.

92. WAVE GEOMETRY.

The total energy radiated from the transmitting antenna a few wavelengths above the earth's surface to a receiver more than a few wavelengths from the transmitting antenna, consists of three parts: the direct wave, the earth-reflected wave, and the ground wave. The sum of the direct and earth-reflected waves is called the space wave. These components are shown in figure 2-43 and are discussed briefly below.

a. **Direct Wave.** The direct wave travels along a direct path from transmitter to receiver and does not require the participation of the troposphere or earth for transmission. The path of the direct wave may be curved slightly by refraction in the earth's atmosphere. Between isotropic (point source) antennas, the direct wave attenuates in accordance with the general equation for free-space or transmission loss:

$$\mathrm{Loss_{dB}} = 10 \log_{10} \frac{P_t}{P_r}$$

Where P_t = Power in watts at transmitting antenna

P_r = Power in watts at receiving antenna

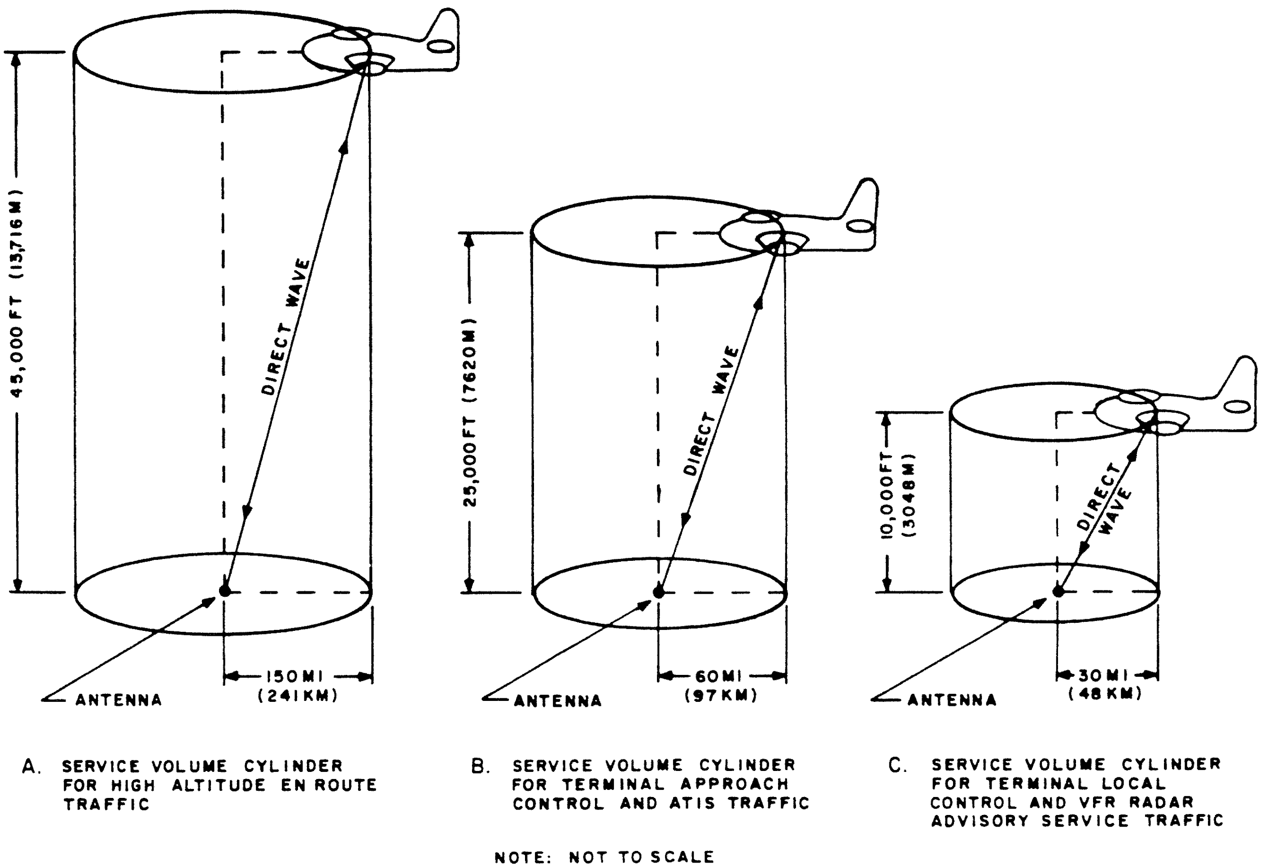


Figure 2-42. Typical Air-Ground Communication Service Volume

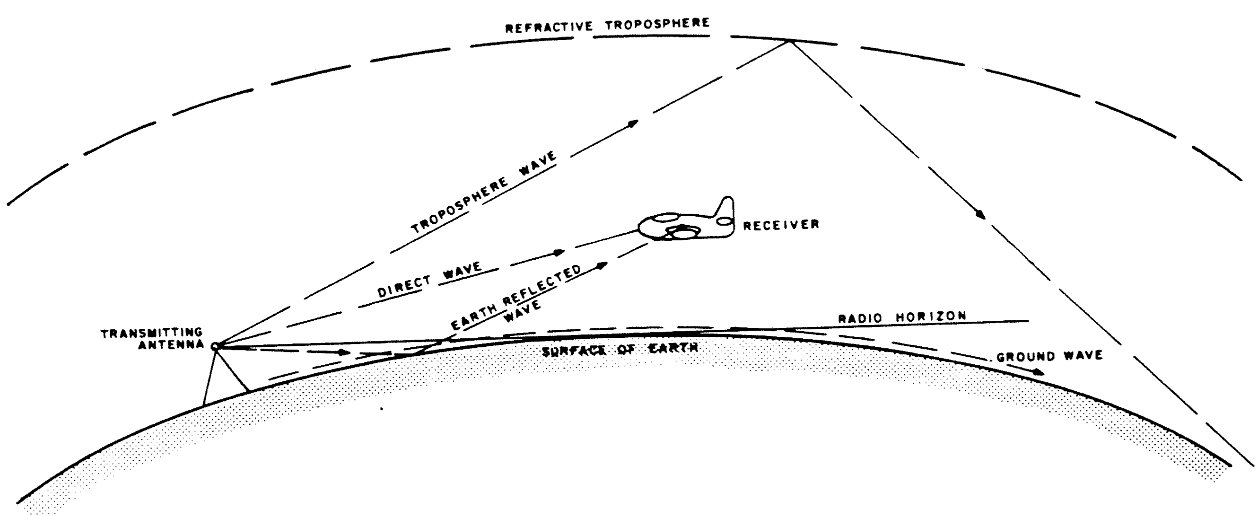


Figure 2-43. Components of VHF and UHF Wave Propagation

The direct wave is the wave on which the service volumes are based.

b. Earth-Reflected Wave. The reflected wave travels to a point on the earth's surface (land or water). After being reflected at an angle equal to the incident angle, the wave travels along another direct path to the receiving antenna. This is called multipath interference, which may possibly cause the receiver to experience a signal loss or cancellation, depending on the comparator lengths of the two paths and the phase of the signals. The speech signal at the receiver may be phase distorted, or there may be fast fading (flutter) affecting intelligibility of speech.

c. Ground Wave. The ground (or surface) wave travels along or near the earth's surface and depends on the presence of the earth for propagation. The ground wave plays almost no part in vhf or uhf a-g communications.

d. Tropospheric Wave. The tropospheric wave is bent in the ionized troposphere (the upper altitude limit of which is about 36,000 feet (10,975 meters)) and is sent back to earth at an angle equal to the angle of incidence. Usually the returned wave suffers a great loss of field strength and will not normally cause interference if returned by a normally ionized troposphere. When this wave is returned by the E region, which may sporadically become highly ionized, it will interfere with receivers at or beyond the radio horizon. The sporadic E mode of propagation is discussed in paragraph 56d.

93. FACTORS AFFECTING COVERAGE.

The service volume is usually not a perfect cylinder, because a number of factors affect coverage and the direct wave suffers additional attenuation, or there is blocking from radio-opaque structures. Siting of antennas and antenna lobing problems, atmospheric absorption, and ducting are factors causing greatest degradation in the received field strength at either the ground or the airborne antenna.

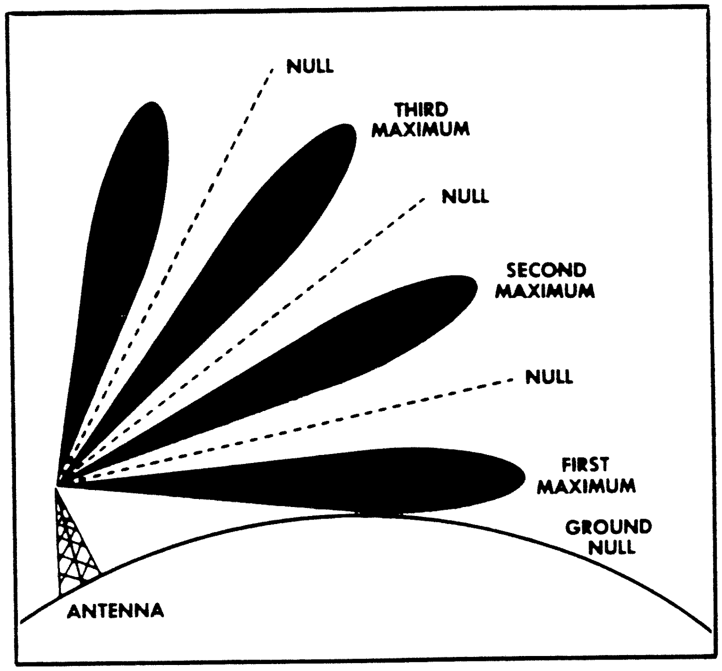
a. Antenna Patterns. Only the theoretical isotropic antenna, a point source, provides a truly omnidirectional radiation pattern. Dipoles and other simple arrays yield some directivity with the result that the receiving antenna will respond less to the wave when oriented in certain directions relative to the orientation of the transmitting antenna. A characteristic of an antenna radiation pattern of significance in a-g propagation is lobing. Lobing can be calculated by considering the antenna to be at various elevations above the reflective earth. Antenna elevation changes to the phase difference between the direct and reflected wave at the distant point of reception. The production of lobes in the antenna patterns, which represent maximum and minimum field strength zones, derives from the fact that if the reflected wave travels an integral number of wavelengths further than the direct wave, the two signals (at the receiver) are in phase and consequently are of greatest signal strength. If an odd number of wavelengths are traveled by the reflected wave farther than the direct wave, they will be in a 180° out-of-phase relationship and thus produce a minimum of received signal strength. As an aircraft travels toward a transmitting antenna on the ground, it will pass through a series of lobe maxima and minima and therefore experience changing received signal strength. See figure 2-45, part A, for an example of the lobe structure over a flat, reflective earth. Antenna pattern contribution to a loss of communication reliability can often be minimized by changing the antenna, providing polarization diversity, or making antenna elevation adjustments. Consideration of aircraft flight paths and the engineering factors necessary to provide an acceptable service volume should be a part of overall system design.

b. Absorption. Radiated energy can be absorbed by vegetation and ground objects as well as by the atmosphere. Although normally not a big problem below 500MHz, absorption will affect the vhf and uhf transmission if the ground-based antenna is located too close to dense, humid vegetation. Heavy rainfall and squall lines are capable of temporarily attenuating vhf and uhf waves. Figure 2-44, part B, illustrates obstruction and absorption effects.

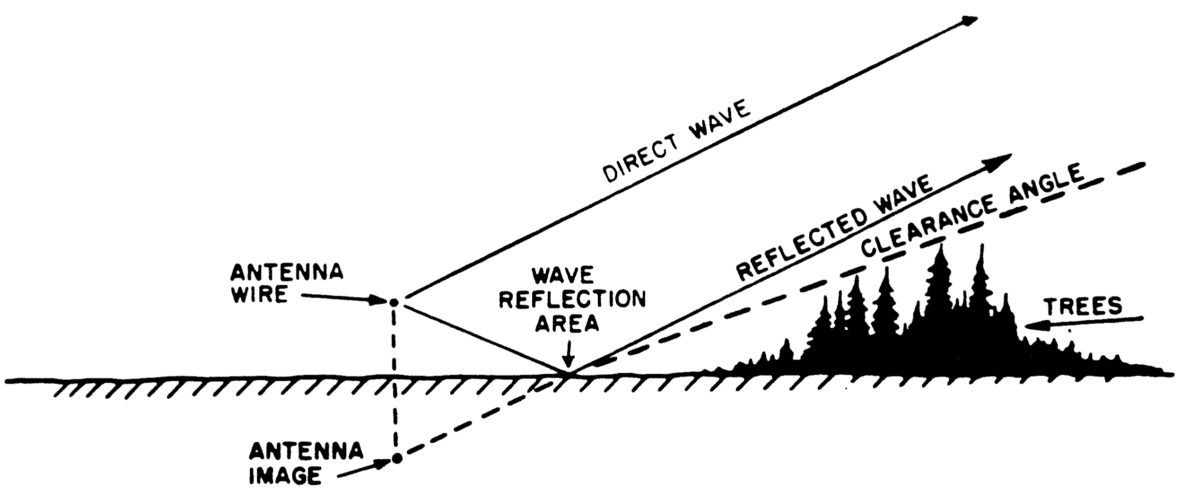
c. Ducting. Ducting results when the normal atmosphere is altered so that the refractive index decreases rapidly with an increase in altitude. This causes a strong downward bending of nearly horizontal waves traveling in the layer. The two types of ducts are the ground-based and the elevated duct. Temperature inversions often produce the ground-based duct. The elevated duct is the result of meteorological subsidence, a slow, downward settling of a large mass of air such as a stagnant high-pressure area, coupled with the horizontal spreading of the air above the lower layers of the atmosphere. The different effects on vhf and uhf propagation depend on whether the transmitting and receiving antennas are located within, above, or below the duct. Two aircraft communicating with each other, if both are within the duct, would probably experience enhanced signal strength. But if one aircraft above the duct is in communication with a ground station or with another aircraft below the duct, there would probably be a decrease in signal strength. The effect on a-g communication should be greatest at or near the extreme limit of the service volume or when communicating with a distant aircraft just above the radio horizon.

94. COVERAGE AND RELIABILITY ANALYSIS.

a. Flight Checks. A flight check using an aircraft flying a circular orbit around a transmitting or receiving facility is a very effective method of determining the range of communication. Either the aircraft or receiving station should be equipped with a strip-chart recorder previously calibrated in



A. LOBING EFFECTS



B. OBSTRUCTIONS AND ABSORPTION

Figure 2-44. Lobing, Obstructions, and Absorption Effects terms of signal strength. It will show effects of additional path loss from obstructions (radio opaque) and multipath problems, including the effects of antenna lobing. An operator on the ground at a ground-based transmitter, using a transit or theodolite, may interrupt the transmitted signal to cause bearing-related markers to appear on the trace on the airborne recorder. Nominally, these will be at 5° or 10° intervals. The effect of airborne antenna attitude and response to ground signal will appear in such checks and must be evaluated. A trailing-wire antenna will eliminate most attitude effects.

b. **Mathematical Analysis.** A computer may be programmed with geological survey data to show radio shadow from land elevations versus antenna location. Because of the transhorizon tropospheric and diffraction effects that modify low-angle line-of-sight propagation, such computer information may be limited in applicability. An effective mathematical evaluation computes path loss and contact reliability to obtain maximum line-of-sight range between the aircraft transmitter (or receiver) and the ground-based transmitter (or receiver). Such computation is similar to the engineering of radio link circuits, where fade margin is the basis on which to determine the statistical reliability of the circuit. This margin is simply the amount of excess rf signal available at the receiver antenna to compensate for the other derogating factors on the system. The fade margin in a-g channels determines the probability of successful (intelligible) contact between the ground and airborne stations. A reliability nomogram is given in figure 4, appendix 8. The following data is used in the wave attenuation and reliability calculations of this paragraph.

Aircraft Contact Probability	Subtract from Isotropic Free-Space Loss
50 percent of contacts are intelligible	0.0dB
90 percent of contacts are intelligible	10dB
99 percent of contacts are intelligible	20dB
99.99 percent of contacts are intelligible	30dB

NOTE: Data is based on a 30-nautical-mile range. Interpolation can be obtained from the nomogram of figure 4, appendix 8.

c. Attenuation and Reliability Calculations. The following is a standard formula for computing the attenuation of a radio path between isotropic (point source) antennas:

$$\text{Path Loss}_{dB} = 38 + 20 \log_{10} f_{MHz} + 20 \log_{10} d$$

where d is line-of-sight distance in nautical miles
f is in MHz (for vhf, the midband frequency 127.5MHz is used)

The constant 38 for the loss between isotropic (point source) antennas cannot be used directly without considering factors such as receiver sensitivity, transmitter power, antenna loss or gain, and total coaxial transmission line loss on each path, ground-to-air and air-to-ground. A sample calculation (subparagraphs (1) and (2) below) for each path shows the methods to be used to apply corrected attenuation. Then, the range is interpreted for expected, or desired, probability of communication. The latter computation determines reliability of actual radio contacts using the channel. For these sample calculations, an aircraft transmitter power of 16W and a ground transmitter power of 10W are assumed. The ground receiver sensitivity is assumed to be –99.0dBm. An assumption is made that 130 feet of coaxial cable type RG-218/U, including other elements such as 10 connectors, one changeover relay, and one rf body (directional wattmeter) collectively introduce a loss of 4.5dB. Aircraft coaxial cable and connector loss is estimated at 5.5dB.

(1) Airborne VHF Receiver and Ground VHF Transmitters. Assume the following data:

Ground transmitter 10W power output	+40dBm
Ground antenna (dipole antenna) loss over isotropic antenna	–0.0dB
Ground coaxial cable, connector, directional wattmeter body, coaxial cavity or other isolation device losses	–4.5dB
Aircraft 1/4-wave whip loss over isotropic antenna	0.0dB
Aircraft coaxial cable and connector loss	–5.5dB
Aircraft receiver sensitivity	+93dBm

NOTE: The total net gains (+) and losses (–) of the above factors yield a range space loss of 123.0dB.

(a) Substituting the range space loss (123.0dB) in the isotropic antenna formula and solving for distance d:

$$20 \log_{10} d = 123.0\text{dB} - 38 - 20 \log_{10} 127.5\text{MHz}$$

$$d = 139.47 \text{ nautical miles maximum line-of-sight range.}$$

This range is theoretically the maximum that will allow a communication reliability of 50 percent.

(b) A reliability of 90 percent modifies by 10dB the range loss, or 123.0dB – 10 = 113.0dB.

NOTE: Standing-wave ratio (swr) must be added to the cumulative losses for cable, connector, and rf wattmeter body. Obtain the swr loss to be added from figure 13, appendix 8.

Substituting in the formula and solving for distance d:

$$20 \log_{10} d = 113.0\text{dB} - 38 - 20 \log_{10} 127.5\text{MHz}$$

$$d = 44.2 \text{ nautical miles maximum line-of-sight range.}$$

(c) To compute the maximum range to be expected for 99 percent reliability, modify the range loss of 123.0dB by 123.0dB – 20dB = 103.0dB.

Substituting in the formula and solving for distance d:

$$20 \log_{10} d = 103.0\text{dB} - 38 - 20 \log_{10} 127.5\text{MHz}$$

$$d = 14.0 \text{ nautical miles maximum line-of-sight range.}$$

(2) **Airborne VHF Transmitter and Ground VHF Receiver.** The gain and loss factors of subparagraph (1) are replaced by:

Aircraft transmitter 16W power output	+42dBm
Aircraft 1/4-wave whip antenna loss over an isotropic antenna	0dB
Aircraft coaxial cable and connector loss	–3.7dB
Ground receiving antenna (broadband coaxial dipole) gain over an isotropic antenna	+0.0dB
Ground receiver coaxial cable, connector, cavity or other isolation device loss	–4.5dB
Ground (AN/GRR-23)) receiver sensitivity (3.0uV = –98.0dBm)	+98.0dBm

For this, the total gains (+) and losses (–) of the above factors yield a range space loss of 131.8dB. Correcting range space loss for 99 percent reliability by 131.8dB – 20dB = 111.8dB. Substituting the corrected range space loss in the isotropic antenna space attenuation formula and solving for distance d:

$$20 \log_{10} d = 111.8\text{dB} - 38 - 20 \log_{10} 127.5\text{MHz}$$

$$d = 38.4 \text{ nautical miles maximum line-of-sight range}$$

(3) **UHF Calculations.** Calculations for UHF links should be made at the midband frequency of 337MHz. The method used is the same as that of (1) and (2) provided that appropriate free-space loss corrections are used.

95.-99. RESERVED.

CHAPTER 3. STANDARDS AND TOLERANCES

100. GENERAL.

This chapter prescribes the standards and tolerances for the remote communication facilities equipment, as defined and described in Order 6000.15A. All key performance parameters and/or key inspection elements are identified by an arrow (→) placed to the left of the applicable item.

101. NOTES AND CONDITIONS.

The following information and suggestions are given to promote uniformity and consistency in making various measurements. They should be referred to when referenced in Section 3, Antennas and Transmission Lines.

a. Where transmitting and receiving equipment are connected to their control point by means of leased or FAA-owned lines, the standards and tolerances and periodic maintenance tests for evaluating the lines are contained in Order 6000.22, Maintenance of Two-Point Private Lines.

b. Excessive modulation and frequency modulation (fm) deviation and off-frequency transmission are potential dangers in the operation of transceiving equipment. The portable or mobile transceivers are usually operated near electronic air navigation or communication facilities that could be adversely affected. Therefore, it is essential that all transceivers be inspected for over modulation and off-frequency crystals in accordance with the standards and tolerances and the maintenance schedules of chapter 4.

c. Insulation resistance cannot be measured in shorted-stub, ba'un-input, or the TACO 2200 series very-high frequency (vhf) and ultra-high frequency (uhf) antennas. These types of antennas are exempt from the standards and tolerances for insulation resistance applicable to other types of antennas. See paragraph 293 for alternate checks.

d. The transmission line alone is measured. It is disconnected from the normal load and an open circuit left between center conductor and shield. The insulation resistance is measured by an insulation tester (megger) connected between center conductor and shield and the line disconnected from the rf body at the sending end of the line.

e. The standing-wave ratio (swr) is measured at the antenna end of the line with the antenna left connected as load. The directional wattmeter rf body is inserted in the line at or very close to the antenna input connector. A dummy load terminating the line in its characteristic impedance shall NOT BE USED for the measurement. The antenna manufacturer's specifications in swr for the particular model of the antenna is the reference initial value at time of commissioning. Actual commissioning value of swr for each antenna and line should be entered in station records for future comparison to determine deterioration.

f. This measurement requires use of an rf or dummy load and directional wattmeter at the antenna location, which may be on top of a tower or tower platform. To enable accomplishment of this check with minimum inconvenience and shutdown of the channel, the check should be scheduled to be accomplished with the check of swr at the antenna end of the line.

g. FAA form 198 records are no longer required. However, commissioning records should be made of coaxial transmission line loss per antenna and all station spares. This will permit comparison at a later date if deterioration is suspected.

h. Unless otherwise indicated, standards and tolerances apply equally to transmitting and receiving antennas and transmission lines, whether the equipment is ground-based, mobile, air-ground, ground-air, or radio link.

i. Dc series resistance cannot be measured in TACO 2200 series and APC vhf and uhf antennas. These antennas are exempt from the standards and tolerances for dc series resistance applicable to other types of antennas.

102. REFERENCES.

Some references in this chapter are to equipment instruction books that have FAA technical issuance (TI) numbers. An example is TI 6620.2A, Receiver, Radio An/GRR-23 and AN/GRR-24. Others are to various manufacturers' instruction books that do not have TI numbers. An example of these is Aerocom IB, par. 5.2.2. References listing only paragraph numbers are found in this handbook.

103.-109. RESERVED.

Section 1. HIGH FREQUENCY EQUIPMENT

Subsection 1. TRANSMITTERS

Parameter	*Reference Paragraph*	*Standard*	*Tolerance/Limit* *Initial*	*Tolerance/Limit* *Operating*
110. MODEL 1330 5KW AM AND SSB TRANSMITTER.	Appendixes 2 and 3			
→ a. **Rated Output Power (M311), Modulation, SWR, and Channel Frequency.**				
(1) Am and ame modes (carrier plus single tone)	240	2025W on meter (5000W PEP)	2025W on meter (5000W PEP)	≥80 percent of initial
(2) SELCAL mode (carrier plus two tones)	240	1500W on meter (5000W PEP)	1500W on meter (5000W PEP)	≥80 percent of initial
(3) Ssb or isb mode (carrier suppressed plus two tones)	240	2025W on meter (5000W PEP)	2025W on meter (5000WPEP)	≥80 percent of initial
(4) Modulation on complex signal (two tone test) at rated PEP	241	No distortion on oscilloscope	Same as standard	Same as standard
(5) Swr (M312)	240	1.0:1	1.5:1 max	1.8:1 max
(6) Channel frequency	243	Assigned frequency	±0.001%	±0.001%
→ b. **Intermodulation Distortion, Third and Fifth Order on 5KW PEP Output.**	242	≥29dB below 2-tone reference level	Same as standard	≥25dB below 2-tone reference level
111. MODEL 1311 1KW AM AND SSB TRANSMITTER.	Appendixes 2 and 3			
a. **Rated Output Power (M403), Modulation, SWR, Channel Frequency.**				
(1) Am and ame modes (carrier plus single tone)	240	1.0 on meter (1000W PEP)	1.0 on meter (1000W PEP)	≥80 percent of initial

Subsection 1. TRANSMITTERS (Continued)

Parameter	Reference Paragraph	Standard	Tolerance/Limit Initial	Operating
(2) SELCAL mode (carrier plus two tones)	240	0.5 on meter (300W PEP)	0.5 on meter (300W PEP)	≥80 percent of initial
(3) Ssb or isb modes (carrier suppressed plus two tones)	240	1.0 on meter (1000W PEP)	1.0 on meter (1000W PEP)	≥80 percent of initial
(4) Modulation on complex signal (two-tone test) at rated PEP	241	No distortion on oscilloscope	Same as standard	Same as standard
(5) Swr (M403)	240	1.0:1	1.2:1 max	1.2 to 1.5:1
(6) Channel frequency	243	Assigned frequency	±0.001 percent	±0.001 percent
→ b. Intermodulation Distortion Third and Fifth Order on 1KW PEP Output.	242	≥29dB below 2-tone reference level	Same as standard	≥25dB below 2-tone reference level
112. MODEL 127-1 CONVERTER-DRIVER.	Appendixes 2 and 3			
a. +28V DC Supply		28.0V dc	28.0V dc	±1.0V
b. RF Output Voltage		10V ac	±1V ac	±2V ac
c. VHF Oscillator Frequency Stability	243	Transmit frequency +64MHz	±0.005 percent	±0.005 percent
→ d. HF Oscillator Frequency Stability	243	Transmit frequency +1750kHz	±10Hz	±10Hz
113. MODEL 125-1 SB AND 125-3 ISB GENERATOR.	Appendixes 2 and 3			
a. RF Output Voltage (TP-C)	240	1.0V ac	1.0V ac	±0.01V
b. Carrier Reinsert Level	240	Max	Max	Max
c. 1750kHz Oscillator Output (TP-A)	243	0.55V ac	0.55V ac	±0.01V
→ d. 1750kHz Oscillator Frequecy Stability	243	1750kHz	±10Hz	±10Hz
114. MODEL GPT-10KW AM AND SSB TRANSMITTER.	Appendixes 2 and 3			

Subsection 1. TRANSMITTERS (Continued)

Parameter	Reference Paragraph	Standard	Tolerance/Limit Initial	Tolerance/Limit Operating
→ a. **Rated Output Power Modulation, SWR (M1005), and Channel Frequency.**				
(1) Am and ame mode (carrier plus single tone)	240	10,000W PEP (5kW avg)	10,000W PEP (5kW avg)	≥80 percent of initial
(2) SELCAL mode (carrier plus two tones)	240	10,000W PEP (5kW avg)	10,000W PEP (5kW avg)	≥80 percent of initial
(3) Ssb or isb mode (carrier suppressed plus two tones)	240	10,000W PEP (5kW avg)	10,000W PEP (5kW avg)	≥80 percent of initial
(4) Modulation on complex signals (two-tone test) at rated PEP	241	No distortion on oscilloscope	Same as standard	Same as standard
(5) Swr (M312)	240	1.0:1	1.2:1 max	1.2 to 1.5:1
(6) Channel frequency	243	Assigned frequency	±0.001 percent	±0.001 percent
b. **PA Section, 10kW AX-509, Balanced Operation.** Antenna I (No. 1 and No.2).	240	See test data	See test	See test data date
→ c. **Intermodulation Distortion Third and Fifth Order on 10kW or 1kW PEP Output.**	242	≥35dB down on spectrum analyzer	≥35dB down on spectrum analyzer	≥35dB down on spectrum analyzer
d. **Oven-Controlled Crystal Oscillator Frequency Stability.**	243	Assigned	±10Hz frequency	±10Hz
115.-117. RESERVED.				

Subsection 2. RECEIVERS

Parameter	Reference Paragraph	Standard	Tolerance/Limit Initial	Tolerance/Limit Operating
118. MODEL 2210 AM AND SSB RECEIVER.	Appendix 2			
→ a. Sensitivity	250	2uV (−101dBm) max, 10mW in 600 ohms	Same as standard	5uV (−93dBm) max, 10mW in 600 ohms
→ b. Squelch	251			
(1) Open		2uV (−101dBm) max to open	Same as standard	5uV (−93dBm) max to open
(2) Close		Approx two-thirds opening value	Same as standard	Same as standard
→ c. Frequency Stability	253			
(1) 1750KHz oscillator, clarifier midrange.		1750Hz	±4Hz	±10Hz
(2) Vhf oscillator		Carrier plus 64Mhz	±0.001 percent	±0.001 percent
(3) Hf oscillator		Carrier plus 1750kHz	±0.001 percent	±0.001 percent
→ d. AM Selectivity	252			
(1) 6dB points		6kHz min	6kHz min	5.8kHz min
(2) 60dB points		14kHz max	14kHz max	15kHz max
(3) Nonsymmetry 60dB points		15 percent max	15 percent max	20 percent max
→ e. Ssb Selectivity	252			
(1) 6dB points		$\geq f_c$ + 2700Hz $\leq f_c$ + 300Hz	Same as standard Same as standard	Same as standard Same as standard
(2) 30dB points		$\leq f_c$	Same as standard	Same as standard

Subsection 2. RECEIVERS (Continued)

Parameter	Reference Paragraph	Standard	Tolerance/Limit Initial	Tolerance/Limit Operating
(3) 50dB points		$\geq f_c$+ 3400Hz	Same as standard	Same as standard
		$\geq f_c$-450Hz	Same as standard	Same as standard
119.-123. RESERVED.				

Section 2. VHF AND UHF EQUIPMENT

Subsection 1. TRANSMITTERS

Parameter	Reference Paragraph	Standard	Tolerance/Limit Initial	Tolerance/Limit Operating
124. VHF AND UHF TRANSMITTERS, TYPES AN/GRT-21, AN/GRT-22, CM-200VT, CM-200UT, AND WT-100.				
→ **a. Output Power**	240			
(1) Low power		10W	±1W	±2W
(2) High power.				
(a) AM-6154/GRT-21 and .... AM-6155/GRT-22 (including linear amplifier).		50W	±2W	35W to 55W
(b) WT-100		Commissioned Value	±1W	±2W
* (c) CM-50/GRT-21 or CM-200VT .... and CM-51/GRT-22 or CM-200VT.		48W	±2W	46 ±4W *
→ **b. Frequency Stability**	243, 236c(9)			
(1) AN/GRT-21/22.				
(a) Oscillator-Multiplier Module ..		Assigned frequency	±0.001 percent	±0.001 percent
(b) Synthesizer Module		Assigned frequency	±0.0005 percent	±0.0005 percent
(2) WT-100		Assigned frequency	±0.0003 percent	±0.0003 percent
(3) CM-200VT/UT		Assigned frequency	±0.0001 percent	±0.0005 percent

Subsection 1. TRANSMITTERS (Continued)

Parameter	Reference Paragraph	Standard	Tolerance/Limit Initial	Tolerance/Limit Operating
125. MISCELLANEOUS PARAMETERS.				
→ a. Modulation Level at Transmitter Output, on 1000Hz Tone or Voice Peaks.	241	95 percent	85 to 95 percent	60 to 95 percent
→ b. VSWR on Transmitter Output	240	1.0/1	1.8/1 max	2.8/1 max
126. HIGH POWER VHF TRANSMITTER, AEROCOM, TYPE 7023.				
a. Output power	240	Commissioned value	±10 percent	±20 percent
b. Channel Frequency	243	Assigned frequency	±0.002 percent	±0.002 percent
c. VSWR	240	1.0:1	1.5:1 max	1.5:1 max
d. Modulation	241	95 percent	85 to 95 percent	60 to 95 percent
127.-130. RESERVED.				

Subsection 2. RECEIVERS

Parameter	Reference Paragraph	Standard	Tolerance/Limit Initial	Tolerance/Limit Operating
131. VHF AND UHF RECEIVERS, TYPES AN/GRR-23 AND AN/GRR-24.				
→ a. Sensitivity	TI 6620.2A	3.0uV (–98dBm) max, 90mW in 600 ohms	3.0uV (–98dBm) max, 90mW in 600 ohms	5uV (–93dBm) max, 90mW in 600 ohms
→ b. Squelch	TI 6620.2A			
(1) Open		1.5uV (–103dBm)	1.5 to 4.0uV (–103dBm to –95dBm)	5.0uV (–93dBm) max

Subsection 2. RECEIVERS (Continued)

Parameter	Reference Paragraph	Standard	Tolerance/Limit Initial	Tolerance/Limit Operating
(2) Close		Approx two-thirds open	Same as standard	Same as standard value
→ c. **Frequency Stability**	TI 6620.2A			
(1) Synthesizer Module		Assigned frequency	±0.0005 percent	±0.0005 percent
(2) Oscillator-Multiplier Module		Assigned frequency	±0.001 percent	±0.001 percent
→ d. **VHF Selectivity and Nonsymmetry.**	TI 6620.2A and Appendix 2			
(1) 50kHz Separation.				
(a) 6dB points		32kHz min	31kHz min	30kHz min
(b) 60dB points		80kHz max	80kHz max	80kHz max
(c) Nonsymmetry, 60dB points		15 percent max	15 percent max	20 percent max
(2) 25kHz Separation.				
(a) 6dB points		20kHz min	16kHz min	14kHz min
(b) 60dB points		50kHz max	50kHz max	50kHz max
(c) Nonsymmetry, 60dB points		15 percent max	15 percent max	15 percent max
→ e. **UHF Selectivity and Nonsymmetry.**	TI 6620.2A and Appendix 2			
(1) 50kHz Separation.				
(a) 6dB points		36kHz min	31kHz min	30kHz min
(b) 60dB points		80kHz max	80kHz	80kHz
(c) Nonsymmetry, 60dB points		60 percent max	60 percent max	60 percent max

Subsection 2. RECEIVERS (Continued)

Parameter	Reference Paragraph	Standard	Tolerance/Limit Initial	Tolerance/Limit Operating
(2) 25kHz Separation.				
(a) 6dB points		20kHz min	16kHz min	14kHz min
(b) 60dB points		50kHz max	50kHz max	50kHz max
(c) Nonsymmetry, 60dB points		60 percent max	60 percent max	60 percent max
f. AVC or AGC Action	254			
(1) Threshold (all vhf and uhf)		5.0uV (–93dBm) max	6.0uV (–91dBm) max	8uV (–89dBm) max
(2) Level control		3dB from 3.0uV to 50,000uV (–97.5dBm to –13dBm)	3dB from 3.0uV to 50,000uV (–97.5dBm to –13dBm)	4dB from 3.0uV to 50,000uV (–97.5dBm to –13dBm)
132. VHF RECEIVERWulfsberg **TYPE WR-100.**	installation operation manual			
→ **a. Sensitivity**		4uV (–96dBm) max 90mW in 600 ohms	4uV (–96dBm) max 90mW in 600 ohms	5uV (–93dBm) max 90mW in 600 ohms
→ **b. Squelch.**				
(1) Open		15dB $\frac{S+N}{N}$	15dB $\frac{S+N}{N}$	±5dB $\frac{S+N}{N}$
(2) Closed		Approx two-thirds open value	Same as standard	Same as standard
→ **c. Frequency Stability.**				
(1) 25kHz separation		Assigned frequency	±0.0003 percent	±0.0003 percent
(2) 50kHz separation		Assigned frequency	±0.0003 percent	±0.0003 percent

Subsection 2. RECEIVERS (Continued)

Parameter	Reference Paragraph	Standard	Tolerance/Limit Initial	Tolerance/Limit Operating
→ **d. Selectivity.**				
(1) 25kHz Separation.				
(a) 6dB points		±9.8kHz min	±9.8kHz min	±9.8kHz min
(b) 80dB points		±21kHz max	±21kHz max	±21kHz max
(2) 50kHz Separation.				
(a) 6dB points		±14.8kHz min	±14.8kHz min	±14.8kHz min
(b) 80dB points		±28kHz max	±28kHz max	±28kHz max
e. AGC Action.				
(1) Threshold		5.0uV (–93dBm) max	6.0uV (–91dBm) max	8.0uV (–89dBm) max
(2) Level control		3dB from 3.0uV to 300,000uV (–97.5dBm to +2.55dBm)	3dB from 3.0uV to 300,000uV (–97.5dBm to +2.55dBm)	3dBm from 3.0uV to 300,000uV (–97.5dBm to +2.55dBm)
133. HIGH-GAIN VHF RECEIVER, AEROCOM, TYPE 8080.				
→ **a. Sensitivity**	Areocom IB, par 5.2.2	0.5uV	0.5uV	1.0uV
→ **b. Squelch**	Aerocom IB, par 5.2.3			
(1) Open		0.5uV	0.5uV	<0.5uV
(2) Closed		Approx 3uV	Same as standard	Same as standard
→ **c. Frequency**	Aerocom IB, par 5.4.3.1	Exact frequency	+0.001 percent	+0.001 percent
→ **d. Selectivity**	Aerocom IB, par 5.4			

Subsection 2. RECEIVERS (Continued)

Parameter	Reference Paragraph	Standard	Tolerance/Limit Initial	Tolerance/Limit Operating
(1) 6dB		15kHz	+1kHz	+1kHz
(2) 60dB		30kHz	30kHz max	30kHz max
e. AGC Action	Aerocom IB, par 5.2.4			
(1) Threshold		1uV	1uV	1uV max
(2) Level control		3dB, 1uV to 500,000uV	Same as standard	Same as standard
* 134. VHF AND UHF RECEIVERS, TYPES CM-200UR AND CM-200VR.				
→ a. Sensitivity	TI 6620.6, TI 6620.7	3.0uV (-98dBm) max, 90mW in 600 ohms	Same as standard	5uV (-93dBm) max, 90mW in 600 ohms
→ b. Squelch	TI 6620.6, TI 6620.7			
(1) Open		1.5uV (-103dBm)	1.5 to 4.0uV (-103dBm to -95dBm)	5.0uV (-93dBm) max
(2) Close		Approx 1.5dB less than open value	Same as standard	Same as standard
→ c. Frequency Stability	TI 6620.6, TI 6620.7	16.8 MHz	±0.0001 percent	±0.0005 percent *

Subsection 2. RECEIVERS (Continued)

Parameter	Reference Paragraph	Standard	Tolerance/Limit Initial	Tolerance/Limit Operating
* → **d. VHF IF Selectivity**	TI 6620.6, TI 6620.7, Appendix 2	-6dB, ±9kHz min. -60dB, ±25kHz max.	Same as standard	Same as standard
→ **e. UHF IF Selectivity**	TI 6620.6, TI 6620.7, Appendix 2	-6dB, ±9kHz min. -60dB, ±25kHz max.	Same as standard	Same as standard
f. AVC or AGC Action	254			
(1) Threshold (all vhf and uhf)		5.0uV (-93dBm) max	6.0uV (-91dBm) max	8uV (-89dBm) max
(2) Level control		3dB from 3.0uV to 50,000uV (-97.5dBm to -13dBm)	Same as standard	4dB from 3.0uV to 50,000uV (-97.5dBm to -13dBm)
135.-139. RESERVED.				*

Section 3. ANTENNAS AND TRANSMISSION LINES

Parameter	Reference Paragraph	Standard	Tolerance/Limit Initial	Tolerance/Limit Operating
140. INSULATION RESISTANCE, ANTENNAS.	101d, i; 290	Infinite	≥50 megohms	≥3 megohms
141. INSULATION RESISTANCE, TRANSMISSION LINES.	101e, i; 291	Infinite	≥50 megohms	≥3 megohms
→ 142. SYSTEM INSULATION RESISTANCE.	101d, i; 291	Infinite	≥50 megohms	≥3 megohms
→ 143. SWR MEASURED AT ANTENNA	101f, i; 261; 262	1.0:1	Manufacturer's specification; if not specified, 2.0:1 max.	3.0:1 max
* IF Motorola LPA CM-50/CM-51				2.0:1 max *
→144. DC SERIES RESISTANCE	101i, j; 292	Zero	Commissioning value	≤5 ohms
→145. TRANSMISSION LINE LOSS	101g, h, i; 260	Manufacturer's specification	≤Manufacturer's specificaton plus 0.5 dB	≤Manufacturer's specificaton plus 1.0 dB
146.-159. RESERVED.				

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CHAPTER 4. PERIODIC MAINTENANCE

160. GENERAL.

This chapter establishes all the maintenance activities that are required for point-to-point (PTP) and air-to-ground (a-g) communications transmitters, receivers, antennas, and transmission lines on a periodic, recurring basis, and the schedules for their accomplishment. The chapter is divided into two sections. The first section identifies the performance checks (i.e., tests, measurements, and observations) of normal operating controls and functions, which are necessary to determine whether operation is within established tolerances/limits. The second section identifies other tasks that are necessary to prevent deterioration and/or ensure reliable operation. Refer to Order 6000.15A for additional general guidance on periodic maintenance.

161.-164. RESERVED.

Section 1. PERFORMANCE CHECKS

Subsection 1. HF TRANSMITTERS

Performance Check	*Reference Paragraph*	
	Standards & Tolerance	*Maintenance Procedures*
* **165. QUARTERLY.**[1]		
a. Power Output. Measure and record results on FAA form 6610-1.	110a; 111a; 114a	240; Appendixes 2 and 3
b. **Modulation Percentage.** Measure with oscilloscope and modulation monitor or voice peaks. Record results on FAA form 6610-1.	110a(4); 111a(4); 114a(4)	241; Appendixes 2 and 3
c. **Standing-Wave Ratio (SWR).** Measure and record results on FAA form 6610-1.	110a(5); 111a(5); 114a(5)	240
* **166. SEMIANNUALLY.**		
a. Measure oven-controlled crystal oscillator frequencies, and record results on FAA form 6610-1.	112d; 113d; 114d	243; Appendix 2
b. Measure miscellaneous crystal oscillator frequencies, and record results on FAA form 6000-8.	112c	243; Appendix 2
* **167. ANNUALLY.**		
a. Measure swr on open wire transmission lines	110a(5); 111a(5); 114a(5)	236a(3), (4); 240e(3)
b. Measure intermodulation distortion (imd), using spectrum analyzer and two tone-test.	110b; 111b; 114c	242; Appendix 2

[1] Certain transmitter parameters may be checked remotely via the RMMS if so equipped, but must be checked semiannually at the transmitter sites.

Subsection 2. HF RECEIVERS

Performance Check	Reference Paragraph: Standards & Tolerance	Reference Paragraph: Maintenance Procedures
168.-169. RESERVED.		
* **170. QUARTERLY.**[1]		*
a. Sensitivity or Noise Figure (NF). Measure and record results on FAA form 6620-1.	118a; Instruction book	250; Appendix 2
b. **Squelch Threshold.** Measure open and close levels, and record results on FAA form 6620-1.	118b; Instruction book	251
c. **Frequency Stability.** Measure oven-controlled crystal oscillator frequencies, and record results on FAA form 6620-1.	118c; Instruction book	253; Appendix 2
d. **Diversity Balance.** Where applicable, observe diversity balance on space-diversity receiving systems, and record results on FAA form 6620-1.	–	236
* **171. SEMIANNUALLY.**		
a. Measure miscellaneous crystal frequencies, and record results on FAA form 6000-8.	118c	253; Appendix 2
b. Reserved.		
172. ANNUALLY.		
a. Measure intermediate frequency (if) amplifier 6dB and 60dB selectivity and 60dB nonsymmetry. Record results on FAA form 6000-8.	118d, e	252; Appendix 2
b. Reserved.		
173.-174. RESERVED.		

[1] Certain receiver parameters may be checked remotely via the RMMS, if so equipped, but must be checked seminannually at the receiver sites. *

Subsection 3. VHF AND UHF TRANSMITTERS

Performance Check	Reference Paragraph: Standards & Tolerance	Reference Paragraph: Maintenance Procedures
* **175. WITHDRAWN–CHG 4** *		
176. SEMIANNUALLY.		
a. Measure the frequency of crystal-controlled oscillators, or measure the transmit frequency at the transmitter output, and record results on FAA form 6600-6.	124b; 126b	243; Appendix 2
b. Measure the synthesizer frequency in types AN/GRT-21, AN/GRT-22, CM-200UR, CM-200VR, and WT-100 transmitters so equipped.	124b; 126b	Instruction book
* c. **RF Power Output at Transmitter.** Measure and record results on FAA form 6600-6.	124a	240; Appendixes 2 and 3
d. **Modulation Percentage.** Observe voice peaks with an oscilloscope and modulation monitor, and record results on FAA form 6600-6.	125a	241; Appendixes 2 and 3
e. **Standing-Wave Ratio (SWR).** Measure the swr at the transmitter output (input to the transmission line). Record results on FAA form 6600-6.	125b	240
177.-179. **RESERVED.**		

*

Subsection 4. VHF AND UHF RECEIVERS

Performance Check	Reference Paragraph: Standards & Tolerance	Reference Paragraph: Maintenance Procedures
180. WITHDRAWN–CHG 4		
181. SEMIANNUALLY.		
a. Measure crystal oscillator frequencies, and record results on FAA form 6530-1 or FAA form 6600-6.	131c, 132c	253; Appendix 2; TI 6620.2A, Par 6.4; Aerocom 8080 IB, Par 5.4.3.1
b. Measure synthesizer frequency in those AN/GRR-23, AN/GRR-24, CM-200 VR and CM-200 UR receivers so equipped.	131c, 134c	TI 6620.2A; Appendix 2 TI 6620.6, TI 6620.7
* c. Perform the following checks on receivers.	131, 132, 133, 134	Appendix 2
(1) **Sensitivity or Noise Figure (NF).** Measure, and record results on FAA form 6600-6.		250
(2) **Squelch Threshold.** Measure squelch threshold level, and record results on FAA form 6600-6.		251
(3) **AVC Action.** Measure the level controls, and record results on FAA form 6600-6.		254

Subsection 4. VHF AND UHF RECEIVERS (Continued)

Performance Check	Reference Paragraph: Standards & Tolerance	Reference Paragraph: Maintenance Procedures
182. ANNUALLY.		
a. Measure if 6dB and 60dB selectivity and 60dB nonsymmetry, and record results on FAA form 6600-6.	131d, e 132d, e 134d,e	252; TI 6620.2A TI6620.6 , TI6620.7 *
* b. Reserved.		
183.-184. RESERVED.		

Subsection 5. ANTENNAS AND TRANSMISSION LINES

Performance Check	Reference Paragraph: Standards & Tolerance	Reference Paragraph: Maintenance Procedures
185. ANNUALLY.		
a. Measure transmission line loss	145	260
b. Measure swr at the antenna	143	261, 262
186.-189. RESERVED.		

Section 2. OTHER MAINTENANCE TASKS

Subsection 1. TRANSMITTERS

Other Maintenance Tasks	Reference Paragraph: Standards & Tolerances	Reference Paragraph: Maintenance Procedures
190. QUARTERLY.[1]		
a. HF Transmitter Tuning and Neutralization.		
(1) Adjust all stages for proper tuning and, if appropriate, neutralization of Class C amplifiers.	–	Instruction Books
(2) Verify frequency change.	110a(6), 111a(6) 114a(6)	243

[1] Certain transmitter parameters may be checked remotely from the RMMS if so equipped, but must be checked semiannually at the transmitter sites.

Section 2. OTHER MAINTENANCE TASKS

Subsection 1. TRANSMITTERS (Continued)

Other Maintenance Tasks	Reference Paragraph	
	Standards & Tolerances	Maintenance Procedures
b. HF Transmitter Automatic Load Control .... Adjust ssb automatic load control (ALC).	–	Instruction Books
* c. Withdrawn ... CHG 2		
d. Withdrawn ... CHG 2		
191. SEMIANNUALLY.	–	Instruction Books
a. Inspect, clean, and, if necessary, replace air filters		
b. Check and adjust air switches for proper operation		
c. Lubricate blower motors of types TV-36, TU-9, FA-7480, and FA-7841 transmitters.		*
192.-194. RESERVED.		

Subsection 2. RECEIVERS

Other Maintenance Tasks	Reference Paragraph	
	Standards & Tolerances	Maintenance Procedures
* 195. SEMIANNUALLY.		*
Inspect, clean, and, if necessary, replace air filters. . . . . Lubricate blowers that are not self-lubricated	–	Instruction Books
196.-199. RESERVED.		

Subsection 3. ANTENNAS AND TRANSMISSION LINES

Other Maintenance Tasks	Reference Paragraph	
	Standards & Tolerances	Maintenance Procedures
200. ANNUALLY.		
a. Measure system insulation resistance	142	291; 293
b. Measure dc series resistance	144	292; Order 6950.22[1]

• U S GOVERNMENT PRINTING OFFICE 1993-0-568-016/80066

Subsection 3. ANTENNAS AND TRANSMISSION LINES

Other Maintenance Tasks	Reference Paragraph	
	Standards & Tolerances	Maintenance Procedures
c. Clean all antenna insulators, replace cracked or broken insulators or other defective parts.	–	–
d. Check operation of antenna heaters, where installed.	–	–
201.-224. RESERVED.		

[1]Order 6950.22, Maintenance of Electrical Power and Control Cables.

CHAPTER 5. MAINTENANCE PROCEDURES

225. GENERAL.

This chapter establishes the procedures for accomplishing the various essential maintenance activities that are required for point-to-point (PTP) and air-to-ground (a-g) communication transmitters and receivers on either a periodic or incidental basis. The chapter is divided into three sections. The first section describes or references the procedures to be used in making the performance checks listed in chapter 4, section 1. The second section describes or references the procedures for doing the tasks listed in chapter 4, section 2. The third section describes the procedures for doing special tasks, usually nonscheduled and not listed in chapter 4. Refer to Order 6000.15A for additional general guidance.

226. INSTRUCTION BOOK REFERENCES.

References are made to certain instruction book procedures or instructions to avoid unnecessary duplication. These references are primarily contained in chapter 3 and 4 tabulations. Instruction book material may be referenced within the procedures or paragraphs of this chapter when necessary to provide additional information.

227. TEST EQUIPMENT.

Refer to the applicable test equipment instruction manuals for conventional usage. Procedures in this chapter do not include step-by-step test equipment adjustments. For built-in or special test equipment, the applicable maintenance procedures include instructions for setting up or adjusting such test equipment. Table 5-1 lists all test equipment necessary to perform the procedures prescribed by this chapter. Refer to Order 6200.4C, Test Equipment Management Handbook, for additional descriptions of test equipment, model numbers, and application information.

228. PHYSICAL REPAIR AND MAINTENANCE OF CABLES.

Order 6950.22, Maintenance of Electrical Power and Control Cables, contains instructions for installing, testing, and physically maintaining and repairing above-ground wire lines and cables owned by the agency. The instructions cover splicing and weatherproofing of coaxial cables, solid and foam dielectric, of the types used in communication antenna systems. When it becomes necessary to replace, splice, or evaluate the condition of new or old cable, refer to Order 6950.22.

Table 5-1. TEST EQUIPMENT

Generic Name	Preferred Item	Substitute Item
Audio power level meter (receiver test set)	General Radio model GR-1840; FA-5515	CA-3432
Audio signal generator	Hewlett Packard model 651A	
Audio distortion analyzer	Hewlett Packard model 339A	
Ac voltmeter	Triplett model 801, type 2	
Dc regulated supply	Trygon model HR40-7C	
Dc voltmeter	Triplett model 801, type 2	
Digital multimeter	Fluke model 8100A	Fluke model 8000

Table 5-1. TEST EQUIPMENT (Continued)

Generic Name	Preferred Item	Substitute Item
Directional wattmeter	Bird model 440 or equal, including rf bodies and elements Aerocom transmitter built-ins	Transmitter built-in
Dummy load, 50-ohm, 25W and 100W, for vhf and uhf transmitters	See Order 6200.4C for details	See Order 6200.4C for details
Electronic frequency counter	Systron-Donner model 6153-50	Systron-Donner model 6151
Frequency counter	Fluke model 1952A	Hewlett Packard 5383A
Function generator (audio oscillator)	Clarke-Hess model 748	Hewlett Packard model 200CD
600-ohm load	Value: ±10%, 1/2 watt	
Microphone	Shure 414B	
Modulation meter	Marconi Instruments model TF 2304	
Oscilloscope	Tektronix model 465 Ballantine model 1066	Oscilloscope, general purpose, dc to 50kHz, single trace
Rf power meter	Coaxial Dynamics model 85	Bird Electronics model 43
Rf signal generator	Hewlett Packard 8640B	Wavetek model 300
Rf isolation pad	Wulfsberg PN 300-2069-000 (WEI DB-1)	
Signal generator	Hewlett Packard HP-608D/E	Hewlett Packard HP-8640B
Spectrum analyzer	Hewlett Packard model H26-8553B	Panoramic Panalyzer model SB-12; Transmitter built-in
Trolley meter (swr meter)	FAA type CA-543A, per drawing CD-C-33-1-2	None
Two-tone test set	Panoramic model TTG-1	None

Tabl~ 5-1. TEST EQUIPMENT (Continu~d

Generic Name	Preferred Item	Substitute
Vacuum-tube voltmeter (vtvm)	Ballantine model 300D Hewlett Packard model 400E	HewlettPackard model 400D; Simpson model 330
Volt-ohm millimeter (vom)	Triplett model 60NA	Simpson model 260; Triplett model 630NA

229.-234. RESERVED.

Section 1. PERFORMANCE CHECK PROCEDURES

235. TECHNICAL PERFORMANCE RECORDS.

The following FAA forms 6000-00, technical performance records (formerly called the FAA form 418 series), shall be used for recording hf, vhf, and uhf transmitter and receiver performance for PTP and a-g communication equipment. The forms are illustrated in figures 5-1 through 5-4. Order 6000.15A provides general instruction on the use of the forms. When necessary to depart from Order 6000.15A instructions, such as for specific equipment application, follow the instructions in paragraph 236.

a. FAA Form 6610-1 (HF Transmitters). Refer to figure 5-1 for a sample of this form.

b. FAA Form 6620-1 (HF Receivers). Refer to figure 5-2 for a sample of this form.

c. FAA Form 6600-6 (VHF/UHF Transmitters and Receivers) Refer to figure 5-3 for a sample of this form.

d. FAA Form 6000-8 (Continuation or Temporary Record/Report). Refer to figure 5-4 for a sample of this form. This form shall be used to record miscellaneous data required by chapter 4. It may also be used, at the discretion of the local maintenance supervisor, to record other necessary information, such as special test data. The columnar arrangement of the form may be altered locally to accommodate certain situations, at the discretion of the local maintenance supervisor.

236. ENTRIES IN TECHNICAL PERFORMANCE RECORDS.

Numerical entries are required for quantitative nominal-line entries. Use checkmarks to denote qualitative conditions and observations that meet observed performance limits. Do not use checkmarks to denote repetitive in-tolerance readings that correspond to a quantitative nominal-line entry or a numerical standard.

a. FAA Form 6610-1.

(1) **Circuit.** Enter the call sign or communication circuit designator.

(2) **Mode.** Enter the operating mode for the equipment and circuit. Refer to paragraph 10 of this order for designations of the authorized modes.

(3) **Ant I_1 and Ant I_2.** Enter the series rf ammeter readings in amperes in each side of the balanced transmission line. These values, when added together and divided by two, yield the average rf current for calculating total output power into the transmission line by the formula $P_t = I_t^2 Z_o$. Transmission line current balance is also obtained by comparing the individual readings of the two ammeters if the transmission line is unbalanced, for example, if it is $Z_o = 50$-ohm coaxial transmission line, enter the forward power directional wattmeter readings under Ant I_1 and reflected power directional wattmeter reading under Ant I_2.

(4) **SWR.** Enter the standing-wave ratio as indicated by the transmitter swr meter or taken from the charts of forward power and reflected power in the transmitter instruction books (or directional wattmeter instruction manual). Forward and reflected power are metered individually in some transmitters. Swr of balanced transmission lines is obtained by using very-low-power channel frequency excitation of open-wire line with a trolley meter.

(5) **Ant Type Indent.** Enter the type of antenna: rhombic, V, sloping V, Yagi, log-periodic, doublet, vertical monopole. The respective abbreviations should be: R, V, S/V, Y, LP, D, VM.

(6) **PA PEP.** Enter the final amplifier peak envelope power obtained from the metered ssb transmitter, based on the chapter 3 standards and tolerances.

(7) **IPA PEP.** Enter the intermediate power amplifier peak envelope power metered at the driver output.

(8) **PA P1 I.** Enter the metered final amplifier plate current in milliamperes.

(9) **PA P1 V.** Enter the metered final amplifier plate voltage in volts.

(10) **PA Scr I.** Enter the metered final amplifier screen current in milliamperes.

(11) **SB Gen RF V.** Enter the sideband exciter or generator rf drive to the converter-driver stage in volts.

(12) **Conv-Drvr RF V.** Enter the converter-driver rf drive to the intermediate power amplifier stage in volts.

(13) **Carr Osc Stability.** Enter the measured oven-controlled carrier oscillator frequency at the sideband generator.

(14) **HF OSC Stability.** Enter the measured oven-controlled high-frequency crystal oscillator in the converter-driver stage.

SSB-AM TRANSMITTER, HIGH-FREQUENCY POINT-TO-POINT/BROADCAST

TECHNICAL PERFORMANCE RECORD

FACILITY	LOCATION (City, State, airport, other)	DATES (From—to)
EQUIPMENT	SERIAL NO. / CIRCUIT / MODE	SUPERVISOR (Signature)

DATE	TIME (GMT)	ANT I_1	ANT I_2	SWR	ANT TYPE IDENT	PA PEP	IPA PEP	PA PL I	PA PL V	PA SCR I	SWR ANT	SB GEN RF V	CONV. DR RF V		CARR OSC STA-BILITY	HF OSC STA-BILITY	STA-TION FREQ STA-BILITY	% MODU-LATION	IMD	REMARKS	INITIALS
NOMINAL																					

SAMPLE

FAA Form 6610-1 (3-79)

Figure 5-1. Sample FAA Form 6610-1

TECHNICAL PERFORMANCE RECORD	SSB–AM RECEIVER, HIGH-FREQUENCY POINT-TO-POINT/BROADCAST				
FACILITY	LOCATION (*City, State, airport, other*)				SUPERVISOR (*Signature*)
EQUIPMENT	SERIAL NO(S).	CIRCUIT	MODE	DIVERSITY	DATE (*From—to*)

DATE	TIME (*GMT*)	SENSITIVITY (μV) OR NOISE FIGURE (dB)				ANTENNA		DIV BAL (V)		OSCILLATOR STABILITY (*Frequency*)								REMARKS	INITIALS
										BEAT FREQUENCY OSCILLATOR				LOCAL OSCILLATOR					
		Rx 1	Rx 2	Rx 3	Rx 4	1 & 2	3 & 4	Rx 1 & 2	Rx 3 & 4	Rx 1	Rx 2	Rx 3	Rx 4	Rx 1	Rx 2	Rx 3	Rx 4		
NOMINAL																			

FAA Form 6620–1 (3–79)

U.S. GOVERNMENT PRINTING OFFICE : 1979—O 291-836

Figure 5-2. Sample FAA Form 6620-1

TECHNICAL PERFORMANCE RECORD

VHF/UHF AIR/GROUND RECEIVERS/TRANSMITTERS

FACILITY	LOCATION *(City, State, airport, other)*			DATE *(From—to)*
TYPE RECEIVER	SERIAL NO.	FREQUENCY	TYPE TRANSMITTER	SERIAL NO. / FREQUENCY / SUPERVISOR *(Signature)*

		RECEIVER									TRANSMITTER					
						SELECTIVITY										
DATE	TIME *(GMT)*	SENSITIVITY µV	SQUELCH THRESHOLD µV	AVC LEVEL CONTROL dB	FREQUENCY	6dB BANDWIDTH	60dB BANDWIDTH	NON-SYMMETRY (%)			POWER OUTPUT WATTS*	VSWR*	FREQUENCY	% MODULATION VOICE	REMARKS	INITIALS
NOMINAL																

**Measure at transmitter.*

U.S. GOVERNMENT PRINTING OFFICE : 1978 - O-291-835

FAA Form 6600–6 (3–79) Formerly FAA Form 6530–1 (3–76) which will be used

Figure 5-3. Sample FAA Form 6600-6

TECHNICAL PERFORMANCE RECORD — **CONTINUATION OR TEMPORARY RECORD/REPORT FORM**

FACILITY (ATCT, FSS, ARTCC, VOR, LOC, ETC.)	DATES FROM TO	SUPERVISOR'S SIGNATURE
LOCATION (CITY, STATE, AIRPORT, OTHER)	EQUIPMENT (A/G, DF, COMPONENTS, ETC.)	FREQ.

DATE	TIME																		REMARKS	INITIALS
NOMINAL																				

FAA Form 6000-8 (3-76) FORMERLY FAA FORM 418-24

U. S. GOVERNMENT PRINTING OFFICE 1976 — 676 156/428/7

Figure 5-4. Sample FAA Form 6000-8

(15) **Station Freq Stability.** Enter the transmitter output carrier or channel frequency, measured from a test point of the transmitter final amplifier or from an attenuator probe in the directional wattmeter.

(16) **Percent Modulation.** Enter the value of A3 mode modulation in percent. In the ssb modes, observe modulation with an oscilloscope, and enter a checkmark if satisfactory.

(17) **IMD.** Enter a checkmark if intermodulation distortion products meet the third- and fifth-order product limits in chapter 3 for the ssb modes of operation.

b. FAA Form 6620-1.

(1) **Circuit.** Enter the call sign or communication circuit designator.

(2) **Mode.** Enter the operating mode for the equipment and circuit. Refer to paragraph 10 of this order for designations of the authorized models.

(3) **Diversity.** Enter yes or no.

(4) **Sens 1 through Sens 4.** Enter the measured receiver sensitivity at the antenna terminals of four diversity receivers (two pairs). The value is to be in microvolts.

(5) **Ant 1/Ant 2; Ant 3/Ant 4.** Enter the antenna type: rhombic, nested rhombic, V, sloping V, Yagi, log-periodic, doublet, wire-grid lens. The respective abbreviations should be: R, N/R, V, S/V, Y, LP, D, WL. The blanks can accommodate two diversity pairs.

(6) **Div Bal.** Enter a checkmark if observation of the diversity combiner-selector metering indicates that each diversity receiver is connected to the system approximately 50 percent of the time.

(7) **SSB/BFO OSC Stab 1 through SSB/BFO OSC Stab 4.** Enter the measured frequency of the oven-controlled ssb beat-frequency oscillator (bfo) crystal oscillator.

(8) **SSB/LO OSC Stab 1 through SSB/LO OSC Stab 4.** Enter the measured frequency of the oven-controlled ssb/local oscillator.

c. FAA Form 6600-6.

(1) **Sensitivity µV.** Enter the measured receiver sensitivity in microvolts.

(2) **Squelch Threshold µV.** Enter the measured rf signal in microvolts required to deactivate the squelch.

(3) **AVC Level Control DB.** Enter this value in dB.

(4) **Frequency.** Enter in MHz the measured first oscillator frequency of the receiver.

(5) **Selectivity.** Enter the measured 6dB and 60dB selectivity of the ITT receiver (6dB and 80dB for the WR-100 receiver).

(6) **Nonsymmetry.** Enter the measured if nonsymmetry of the receiver in percent.

(7) **Power Output Watts.** Enter the measured power output in watts of the transmitter, into the normal transmission line/antenna load of the channel.

(8) **VSWR.** Enter the swr measured at the transmitter output with the thru-line wattmeter.

(9) **Frequency.** Enter the measured station (on-the-air) frequency of the transmitter, measured at a directional coupler inserted at the transmitter output, when connected to the normal transmission line/antenna load.

(10) **% Modulation Voice.** Enter the peak voice modulation on an active channel, measured with the modulation monitor and oscilloscope.

237. AURAL MONITORING.

Aura monitoring of speech transmission on an a-g channel provides a means to determine the usability of the channel. Off-the-air monitoring, using a vhf or uhf receiver, can provide, from a remote point, an indication of the quality of the entire a-g channel from microphone to transmitter. The preferred method for aural monitoring at the remote outlet is to connect a headset receiver via a bridging amplifier across the circuit and listen to the controller's or pilot's transmissions. It is important that only bridging (high impedance) connections be made and under no circumstances, on an operational channel, should the headset be patched into line or equipment jacks that will open the channel.

238.-239. RESERVED.

Subsection 1. TRANSMITTER CHECKS

240. TRANSMITTER OUTPUT POWER AND STANDING-WAVE RATIO (SWR).

a. Object. To measure the transmitter output power into the transmission line feeding the antenna.

b. Discussion. Output power is measured with directional wattmeters in an unbalanced transmission line, such as coaxial cable, or with series rf ammeters in each side of a balanced transmission line, such as open-wire line. The directional wattmeters are either direct reading, or the power is interpreted with a chart from which swr can also be determined. The series ammeters are read individually, and the readings are added together and divided by two. The average current obtained from this is then used in a simple calculation to obtain total power developed in the nominal impedance Z_o of the transmission line.

c. Test Equipment Required. Usually none; the directional wattmeter is, typically, built-in equipment. For swr checks of open-wire transmission lines, a trolley meter is used.

d. Conditions. For most power determination, no shutdown is required. If shutdown is required, coordinate it with the air traffic watch supervisor before proceeding.

e. Detailed procedures.

(1) Using the Directional Wattmeter (Figure 1, Appendix 2).

(a) In equipment using a single meter for forward power and reflected power, note the reading when the selector switch is in the forward power position. Record the reading in watts on FAA form 6610-1.

(b) Select the reflected power position of the meter switch and record the reading in watts.

(c) With the directional wattmeter chart plotted in percent reflected power versus swr (refer to page 25 of the model 1330 5kW ssb transmitter instruction manual for an example), enter the chart with percentage of reflected power calculated with the formula:

$$\text{Percentage of } P_r = \frac{P_r}{P_f} \text{ X } 100$$

where P_f and P_r are forward and reflected power values from step (a) and (b) above. Read swr from the horizontal axis as intercepted on the curve in the chart.

(d) With a directional wattmeter chart plotted directly from reflected and forward power readings, enter the chart on the horizontal and vertical axes and read the swr curve intercepted.

(e) In the absence of charts, the swr can be computed from readings of forward and reflect power by the formula:

* $$Swr = \frac{\sqrt{P_f}+\sqrt{P_r}}{\sqrt{P_f}-\sqrt{P_r}}$$ *

(f) For transmitters having individual meters for forward and reflected power, the procedure is the same as in steps (a) through (e) for obtaining power and swr, except that no meter switching is involved. Some transmitters have direct-reading swr meters that may be used.

(g) For transmitters having both a final output amplifier swr meter and an antenna output swr meter, record both meter indications on FAA form 6610-1. The applicable tolerance shall apply to both readings.

(2) Using Series RF Ammeters in Open-Wire Line (Figure 1, Appendix 2).

(a) Read the antenna current in rf amperes in each line, and enter the reading on FAA form 6610-1.

(b) Calculate the transmitter total average output power, based on the average antenna current, with the following formula:

$$Pt = \left(\frac{I_1 + I_2}{2}\right)^2 \quad Z_o$$

(c) Compute power as PEP from average power obtained in step (b):

$$PEP = P_t \text{ X } 2$$

Enter the results in the PEP column of FAA form 6610-1.

EXAMPLE: I_1 = 3.1 amperes

I_2 = 2.8 amperes

Z_o = 600-ohm nominal for rhombic transmission lines.

$$P_t = \left(\frac{3.1 + 2.8}{2}\right)^2 \text{ X } 600$$

$$= 5221.5 \text{ watts, average}$$

$$
\begin{aligned}
PEP &= P_t \times 2 \\
&= 5221.5 \times 2 \\
&= 10{,}443.0 \text{ watts, PEP}
\end{aligned}
$$

(3) Using the Trolley Meter for SWR on Open-Wire Line (Figure 5-5). To determine swr on open-wire transmission line, such as the 600-ohm feeders used for rhombic and other PTP antennas, a trolley meter is required. The swr check is usually made between the location of the stub nearest the transmitter building and the feed-through insulators in the side of the building. This ensures that the transmitter is loaded with the correct impedance and low-swr conditions. Figure 5-5 shows a typical trolley meter in use on the stubbed transmission line.

(a) The power fed to the line under test must be low and just enough to deflect the meter in the trolley meter to about two-thirds of full scale. An rf signal generator may have enough output for the job. The generator is loop-coupled into the output tuner of the transmitter, which must be shut down, and the high voltage must be removed from all stages. The trolley meter is drawn up and down along one side of the line outside the building to obtain a peak reading. As the trolley meter is moved, the meter maximum reading and minimum reading corresponding to the standing-wave peaks and troughs are recorded. The meter deflections cannot be used directly if a square-law detector is involved. The swr is obtained from the formula:

$$\text{swr} = \frac{\text{maximum meter deflectiion}}{\text{minimum meter deflection}}$$

EXAMPLE: Meter maximum
scale deflection = 29

Meter minimum
scale deflection = 25

Substituting: swr

= 29/25

= 1/.16

= 1.08

(b) A non-square-law trolley meter is accompanied by a chart for the relation of meter deflection to electric field. For these trolley meters, the actual meter deflection must be converted to the chart value for use in the above formula.

241. TRANSMITTER AUDIO MODULATION LEVEL AND PERCENTAGE.

a. Object. To check the maximum undistorted audio modulation of the transmitter.

b. Discussion.

(1) Modulation checks for ssb and am transmitters are accomplished by using different techniques. Refer to appendix 2 for a discussion of ssb modulation. Appendix 3 contains test arrangements and nomographs for measuring modulation for am transmitters of vhf and uhf a-g channels. Modulation in ssb transmitters is determined by using an oscilloscope. Figure 2-9 (and figure 3 of appendix 2) illustrates normal and abnormal ssb modulation patterns.

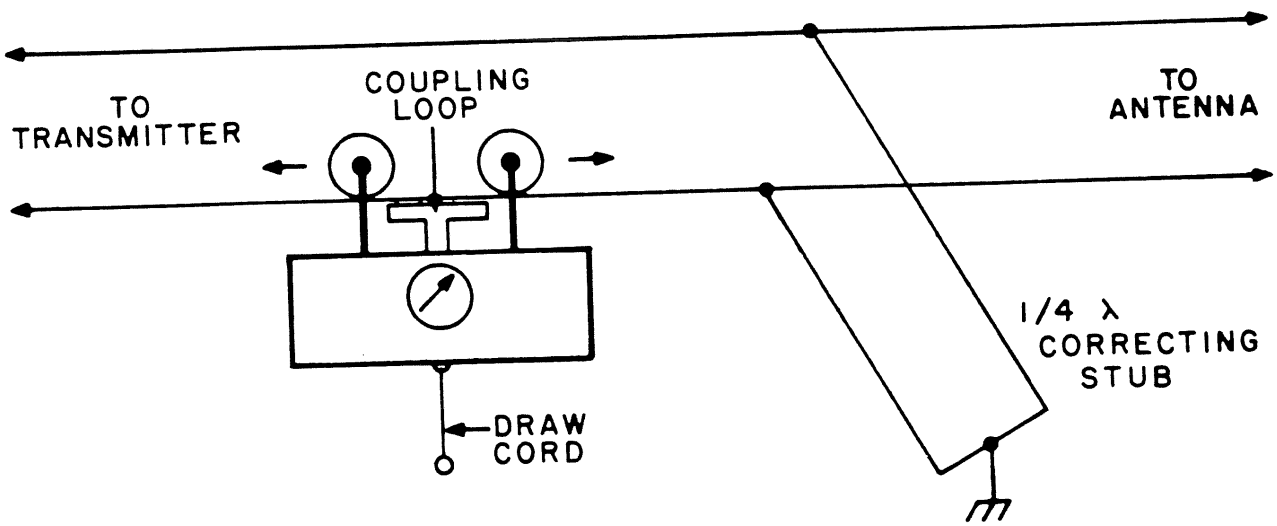


Figure 5-5. SWR Test on Open-Wire Transmission Line

(2) To check modulation on active channel without shutdown, an oscilloscope and modulation monitor can be connected without the use of a dummy load. When adjusting 1000Hz test-tone modulation sensitivity, shut down the transmitter, and replace the antenna with a dummy load of the proper power dissipation.

c. Test Equipment Required.

(1) Oscilloscope.

(2) Audio oscillator, function generator, or two-tone test set.

(3) Modulation monitor.

(4) Dummy load.

(5) Directional wattmeter and elements.

(6) Audio power level meter.

d. Conditions. When shutdown is required, coordinate it in advance with the air traffic watch supervisor.

e. Detailed Procedures.

(1) Checking Ssb Modulation (Figure 5-6).

(a) Connect the test equipment as shown in figure 5-6. At certain installations, this arrangement may be built in with the transmitting equipment.

(b) Apply a low-level audio signal, 1000Hz at −30dBm or less, to the input of the ssb generator or exciter, and gradually increase this level while observing the oscilloscope. Continue to increase level just until flat-topping is observed on the oscilloscope waveform, with full transmitter PEP.

(c) Record the level at which flat-topping occurs.

(d) Back off the audio input level just until flat-topping disappears. This is the maximum modulation audio input level. If this level agrees with the level commissioned for audio input, enter a checkmark on FAA form 6610-1.

(2) Checking AM Percentage (Figures 2 through 5, appendix 3).

(a) From appendix 3, select the test setup required.

(b) Apply a 1000Hz audio sine wave test tone to the transmitter modulator input at the level required for the appropriate interface level.

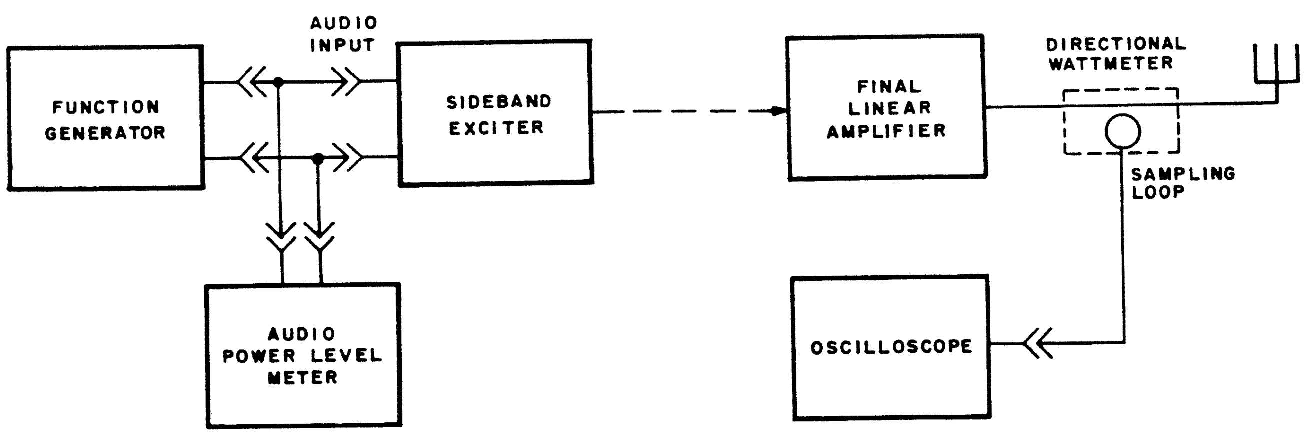


Figure 5-6. Checking Ssb Modulation

(c) Observe the modulation monitor-oscilloscope pattern and determine the modulation percentage. Adjust modulator gain as required to meet the limits of chapter 3.

(d) Record results on FAA form 6610-1 or FAA form 6600-6.

f. Detailed Procedure for WT-100 Transmitter. See section 4.4.5 of the manufacturer's instruction book for detailed procedures.

242. SPURIOUS EMISSIONS AND INTERMODULATION DISTORTION (IMD).

a. Object. To ensure that the transmission adequately supresses unwanted radiation and that intermodulation distortion (imd) products are within prescribed limits.

b. Discussion.

(1) Spurious emission is usually emitted by a transmitter outside the message signal band of the transmitter. Parasitics, harmonics, harmonics of imd products, and imd products are some causes of spurious emission. The most troublesome imd are the third- and fifth-order products. Refer to appendix 2 for a discussion of imd.

(2) Some transmitters are equipped with the spectrum analyzer, the basic test equipment item for detecting spurious emission. Where these are not permanently installed, they may be obtained as portable test equipment. The procedure given below applies to most ssb applications and available models of spectrum analyzers. The portable spectrum analyzer should be connected to a sampling loop probe in the transmitter output directional wattmeter body.

c. Test Equipment Required.

(1) Spectrum analyzer, or Panalyzer.

(2) Two-tone test set.

(3) Vom and/or vtvm.

d. Conditions. Transmitter shutdown will be required when a two-tone audio test signal is applied to the sideband exciter. Coordinate the shutdown with the air traffic watch supervisor before proceeding.

e. Detailed Procedure for Measuring IMD (Figure 5-7).

(1) Warm up the spectrum analyzer and obtain a trace on its cathode-ray tube (crt). Set for a logarithmic presentation.

(2) Ensure that the transmitter is operating at rated PEP and that metered stages are performing satisfactorily. Reduce sideband exciter or converter-driver output to zero.

(3) Remove the normal audio input and apply, at the same audio level, the output of the two-tone test generator to the audio modulation input of the sideband exciter.

(4) Increase the sideband exciter output to return the transmitter to full PEP.

(5) Set the spectrum analyzer input gain so that the peaks of the two tones are at 0 dB on the display vertical scale. The displays of figure 3, part A, in appendix 2 should be obtained.

(6) Check for the presence of imd signals along the baseline and observe the relative amplitudes of the carrier, and third- and fifth-order products. If within tolerance, enter a check mark on FAA form 6610-1. These products should be equal to or less than the limit established in paragraphs 110b, 111b, and 114c of chapter 3. Abnormalities such as shown in parts B and C of figure 3, appendix 2, should be corrected.

243. FREQUENCY STABILITY.

a. Object. To ensure that the transmitter crystal oscillator frequencies are within tolerance.

b. Discussion. Particularly in the ssb transmitter, the crystal-controlled oscillators that determine the carrier frequencies must be held very closely within tolerances specified in chapter 3. This permits exact reinsertion of the suppressed carrier at the receiver and prevents signal distortion.

c. Test Equipment Required.

(1) Electronic frequency counter.

(2) Insulated screwdriver.

d. Conditions. If frequency adjustments are required, the transmitter will be shut down. Coordinate shutdown with the air traffic watch supervisor.

e. Detailed Procedure, Ssb Transmitter Models 1330 and 1311.

(1) Warm up the electronic frequency counter for at least 15 minutes.

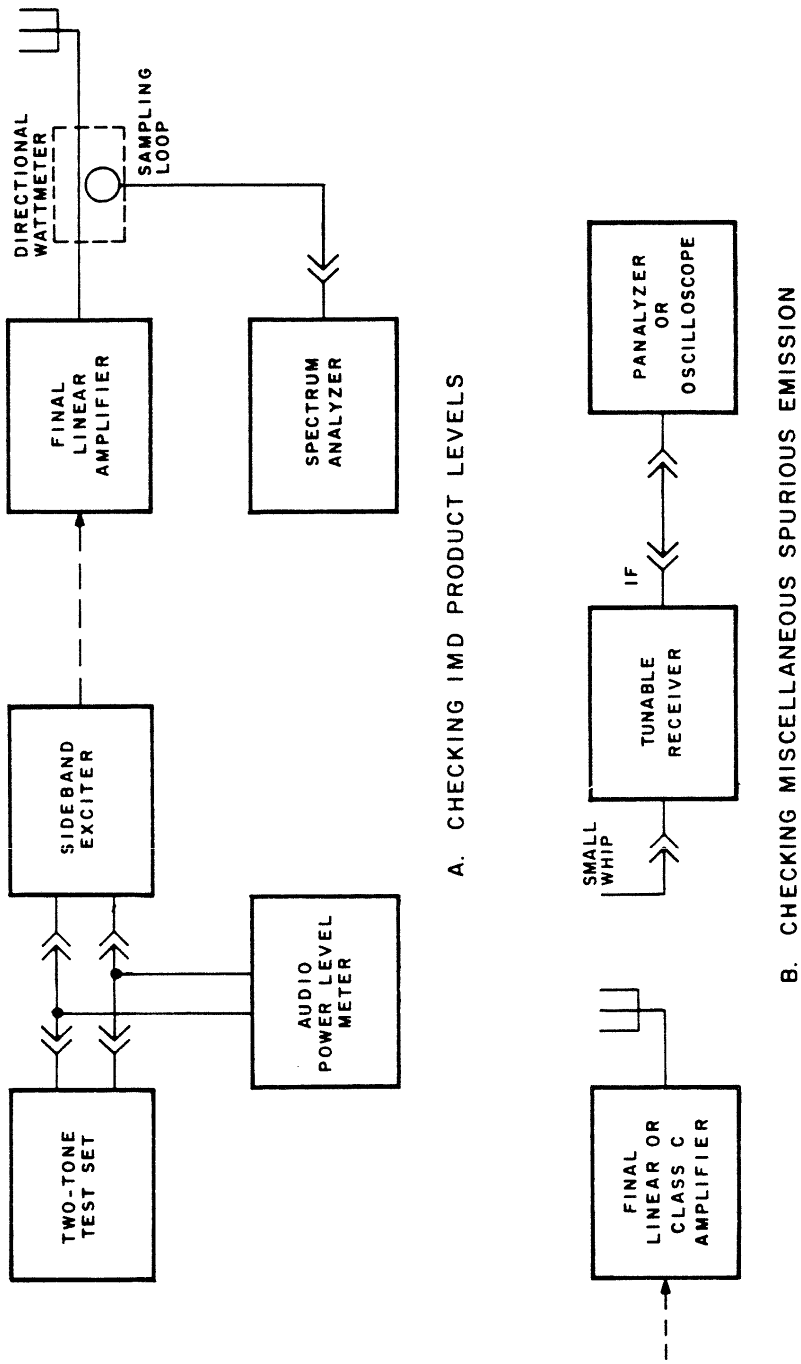


Figure 5-7. Checking IMD and Spurious Emission

(2) Adjust the frequency range of the counter to the frequency of measurement, and make the tests using the following test points of the transmitter:

CAUTION: To avoid damaging a counter, ensure that a proper dc blocking capacitor is used at the counter input.

(a) **Channel Frequency.** Connect the counter input to a sampling loop in the directional wattmeter body. Reinsert the carrier if operating with a suppressed carrier. After measurement, disconnect the counter and resuppress the carrier.

(b) **Transmitter HF Oscillator, Transmit Frequency + 1.750MHz.** Connect the counter to the hf oscillator output terminal. Adjust, if necessary, capacitor F of the selected channel for exactly the transmit frequency of step (a) + 1.750MHz. After completion, disconnect the counter.

(c) **VHF Oscillator, Transmit Frequency + 64MHz.** Connect the counter to the vhf oscillator OUT terminal. Adjust, if necessary, L81 and C82 exactly for the transmit frequency + 64MHz. After completion, disconnect the counter.

(d) **1750kHz Oscillator.** Connect the counter to test point A at the output of the buffer amplifier in the type 125-1 (ssb) or type 125-3 isb generator. Adjust, if necessary, C81 for exactly 1750kHz. After completion, disconnect the counter.

f. Procedure for Miscellaneous Transmitters. The required frequency stability for am hf, vhf, and uhf transmitters may be checked for channel frequency (transmit frequency) as in step (a) of paragraph e above. Substage crystal oscillator frequency checks require locating the output of the oscillator that is driving the mixer circuit and coupling into this circuit with a dc blocking capacitor to prevent possible damage to the counter input circuit. To obtain the best test point for such measurements, refer to the individual schematic diagrams of the transmitters, located in the equipment instruction books.

244.-249. RESERVED.

Subsection 2. RECEIVER CHECKS

250. SENSITIVITY.

a. Object. To ensure that the receiver will respond to a specified input level in microvolts for a specified audio power output level, or for a specified signal-plus-noise to noise ratio at the audio output.

b. Discussion. A receiver may deteriorate in performance from defective components, changes in tuned circuits, or changes in operating voltage. This deterioration is reflected in lowered sensitivity or gain.

c. Test Equipment Required.

(1) Signal generator or communications service monitor (CSM).

(2) Audio power level meter or receiver test set.

d. Conditions. Receiver sensitivity is the microvolt level required to produce a signal-plus-noise (signal generator modulation on at 1000Hz, 30 percent) to noise alone (signal generator modulation off) ratio of 10dB. This is a power ratio of 10:1 and a voltage ratio of 3.16:1.

e. Detailed procedure for AM Receivers.

(1) Connect the test equipment as shown in figure 5-8, and allow a warmup of at least 15 minutes.

(2) Turn the receiver squelch control to OFF and the audio gain control to maximum (fully clockwise).

(3) Adjust the signal generator or CSM for 1000Hz modulation at 30 percent.

(4) Adjust the generator to the exact channel frequency.

(5) Adjust the generator output until the receiver output caused by the rf signal voltage exceeds the noise level by at least 50mW. Peak the receiver's antenna trimmer.

(6) Set the generator output for the level in dBm from the applicable initial or operating tolerance specified in chapter 3.

(7) Set the receiver's audio gain control to obtain the audio power level specified in chapter 3.

(8) Shut off the tone modulation of the generator.

(9) Without changing the receiver's audio gain control, vary the generator rf output level while observing the audio power output on the power level meter. At the same time, turn the tone modulation on and off. When a ratio of 10:1 (modulation on:modulation off) is obtained, record the generator output attenuator setting. This will be the value in dBm or microvolts representing the required sensitivity stated in the applicable paragraph of chapter 3. If not within the stated tolerance/limit, troubleshooting of the receiver is required.

(10) If tolerance/limit is met, the test for receiver squelch threshold can be performed, as test equipment arrangement is the same.

251. SQUELCH THRESHOLD.

a. Object. To determine receiver quieting in the absence of a received signal.

b. Discussion. The test arrangement for sensitivity, shown in figure 5-8, is also used for squelch-action checks.

c. Test Equipment Required.

(1) Signal generator or CSM.

(2) Audio power level meter or receiver test set.

d. Detailed Procedure.

(1) Connect the test equipment as shown in figure 5-8, and allow a warmup of at least 15 minutes unless a sensitivity check has just been accomplished.

(2) Turn the receiver squelch control to ON.

(3) Adjust the signal generator or CSM rf output to zero. Observe the receiver noise output on the audio power level meter. The receiver noise should be quieted.

(4) Gradually increase the generator output until the squelch deactivates (opens). This level in dB or microvolts is the squelch threshold.

(5) If tolerances/limits are met, and no other checks are to be performed, disconnect the test equipment and restore the receiver to service. Peak the receiver's antenna trimmer for maximum agc using an on-the-air signal.

e. Detailed Procedure for WR-100 Receivers. See paragraphs 4.3.8 and 4.3.9 of the manufacturer's instruction book.

252. SELECTIVITY AND NONSYMMETRY MEASUREMENTS.

a. Object. To determine the if amplifier and crystal filter minimum selectivity at the 6dB points and the maximum selectivity at the 60dB (80dB for WR-100) points. This procedure also measures the percent of nonsymmetry at the 60dB points.

b. Discussion.

(1) Selectivity is a measure of the receiver's ability to reject unwanted signals. Nonsymmetry checks ensure that faulty circuits do not distort the selectivity response to cause loss of fidelity in the desired signal or loss of contact.

(2) Selectivity and nonsymmetry checks of am receivers are different from those applied to ssb receivers in that frequency offsets in the mixer to if amplifier chains must be considered.

c. Test Equipment Required.

(1) Rf signal generator or CSM.

(2) Vtvm, vom, or digital multimeter.

(3) Electronic frequency counter if CSM is unavailable.

d. Detailed Procedures.

(1) Procedure for AM Receivers (Figure 5-9).

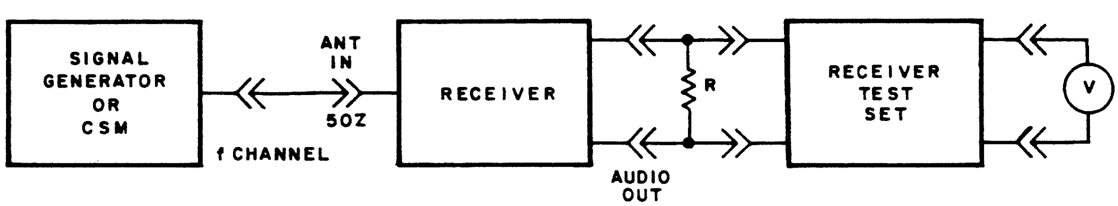


Figure 5-8. Checking Receiver Sensitivity and Squelch Threshold

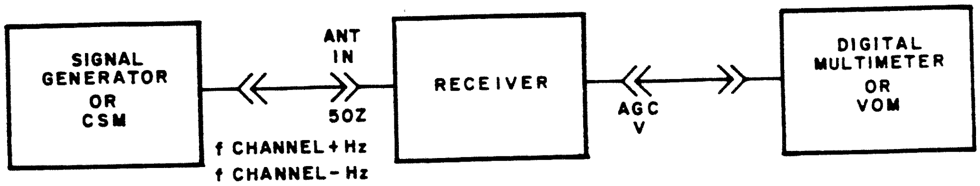


Figure 5-9. Checking Receiver Selectivity and Nonsymmetry

(a) Turn the receiver and the signal generator or communications service monitor (CSM) power on, and allow a warmup of at least 15 minutes. Turn the receiver squelch off.

(b) Connect the 50-ohm signal generator or CSM cable to the antenna connector. Set the generator modulation to off and the rf output attenuator for zero output.

(c) Connect the volt-ohm milliammeter or digital multimeter test leads between the agc voltage and ground.

(d) Adjust the signal generator or CSM to the exact channel frequency. Use an electronic frequency counter to monitor all frequency adjustments if the CSM is not available.

(e) Slowly increase the signal generator or CSM rf output from zero until the vom indicates agc action has just begun. Record this voltage as the agc reference voltage. DO NOT OVERDRIVE THE AGC CIRCUIT DURING THIS STEP. Note the level of rf output in dBm on the generator or CSM output attenuator dial.

(f) Increase the generator or CSM rf output by 6dB on the output attenuator dial.

(g) Carefully increase the signal generator or CSM output frequency (above the channel frequency) until the agc reference voltage of step (e) is again obtained on the vom. Record the generator or CSM output frequency.

(h) Carefully reduce the signal generator or CSM output frequency (below the channel frequency) until the agc reference voltage of step (e) is again obtained. Record the generator or CSM output frequency.

(i) Compute the bandwidth at the 6dB points by subtracting the lower of the two recorded frequencies (steps (g) and (h)) from the higher frequency.

(j) Increase the output of the signal generator or CSM over the value of step (e) by 60dB (80dB for the WR-100 receiver).

(k) Repeat steps (g) and (h) in turn, recording the generator output frequencies for each.

(l) Compute the bandwidth at the 60dB points by subtracting the lower of the two recorded frequencies (steps (g) and (h)) from the higher frequency.

(m) Compute nonsymmetry in percent as follows:

Percent nonsymmetry = $(\Delta f_1/\Delta f_2) - 1 \times 100$

Where Δf_1 = difference between channel frequency and the frequency below channel frequency at which 60dB attenuation occurs.

Δf_2 = difference between channel frequency and the frequency above channel frequency at which 60dB attenuation occurs.

If Δf_2 is larger than Δf_1:

Percent nonsymmetry = $(\Delta f_2/\Delta f_1) - 1 \times 100$

(n) Refer to chapter 3 for limits for selectivity and nonsymmetry.

EXAMPLE (perfect symmetry):

Δf_1 = 40kHz at the 60dB point higher than channel center frequency

Δf_2 = 40kHz at the 60dB point lower than channel center frequency

Substituting:

$$\text{Percent nonsymmetry} = [(\Delta f_1/\Delta f_2) - 1] \text{ X } 100$$

$$= (\ 40/40 \ ) - 1 \text{ X } 100$$

$$= 1 - 1 \text{ X } 100 = 0\%$$

EXAMPLE (symmetry in tolerance):

Δf_1 = 43kHz at the 60dB point higher than channel center frequency.

Δf_2 = 40kHz at the 60dB point lower than channel center frequency.

Substituting:

$$\text{Percent nonsymmetry} = (\Delta f_1/Df_2) - 1 \text{ X } 100$$

$$= (\ 43/40 \ ) - 1 \text{ X } 100$$

$$= 1.075 - 1 \text{ X } 100 = 7.5\%$$

EXAMPLE (symmetry out of tolerance):

Δf_1 = 47kHz at the 60dB point higher than channel center frequency.

Δf_2 = 38kHz at the 60dB point lower than channel center frequency.

Substituting:

$$\text{Percent nonsymmetry} = [\Delta f_1/\Delta f_2) - 1] \text{ X } 100$$

$$= (\ 47/38 \ ) \text{28M} - 1 \text{ X } 100$$

$$= 1.2368 - 1 \text{ X } 100 = 24\%$$

(2) Procedure for Aerocom Ssb Type 2210 Receiver. Selectivity measurements in type 2210 receiver am mode are performed the same as for vhf and uhf am receivers (subparagraph 1)). For this measurement, the agc reference voltage is obtained at the agc output of the 1750kHz if amplifier card.

(a) Adjust the signal generator or CSM for an output frequency of carrier frequency + 1000Hz.

(b) Adjust the generator rf output to obtain approximately +6V at the agc output. Record this level as the agc reference voltage.

(c) Increase the generator rf output 6dB.

(d) Lower the generator output frequency to obtain the agc reference of step (b) and record the frequency of the generator.

(e) Increase the generator output frequency through the peak of the if response until the same agc reference of step (b) is again obtained. Record the higher frequency.

NOTE: The higher frequency should be greater than the carrier frequency +2700Hz. The lower frequency (step (d)) should be less than the carrier frequency +300Hz.

(f) Increase the generator rf output to 30dB above the reference level.

(g) Lower the generator frequency output to again obtain the agc reference level. Record this frequency. It should be less than or equal to carrier frequency.

(h) Increase the generator rf output to 50dB above the reference level.

(i) Lower the generator frequency output to again obtain the agc reference level. Record the frequency.

(j) Increase the generator output frequency to obtain the agc reference level. Record the frequency. The higher and lower frequencies should be as stated in the standards and tolerances table.

253. FREQUENCY STABILITY.

a. Object. To ensure that the output of the first crystal oscillator, or all oven-controlled oscillators in ssb receivers, is within required tolerances or limits.

b. Test Equipment Required.

(1) Electronic frequency counter or CSM.

(2) Digital multimeter (for ssb receiver).

c. Discussion. Frequency accuracy of the first or local oscillator of vhf and uhf receivers is important for operational performance of the receivers in a 50kHz or 25kHz channel spacing. For ssb receivers, frequency accuracy is of extreme importance in suppressed-carrier modes to enable the receiver to properly demodulate the received signal.

d. Detailed Procedure for Type AN/GRR-23 and AN/GRR-24 Receivers. A complete oscillator test procedure is located in paragraph 6-4 of Instruction Book TI 6620.2A, Receiver, Radio, AN/GRR-23 and AN/GRR-24, Volume 1.

e. **Detailed Procedure for Type WR-100 Receivers.** A complete oscillator test procedure is located in paragraph 4-4.2.3 of the Wulfsberg installation-operation manual.

f. **Detailed Procedure for Aerocom Type 2210 Ssb/AM Receiver.**

(1) Connect the counter to the 1750kHz oscillator output, J4, at the rear of the receiver.

(2) Measure the frequency. If it is not exactly 1750.000kHz, adjust capacitor C1 on the 1750.000kHz oscillator, with the clarifier control at midposition, for exactly 1750.000kHz. *

(3) Connect the counter to the hf oscillator output, J6, at the rear of the receiver.

(4) Measure the frequency of the crystal. If the crystal frequency is out of initial tolerance, adjust C1 on the hf oscillator for the exact crystal frequency.

(5) Connect the counter to vhf oscillator output, J5, at the rear of the receiver. Connect a digital multimeter to TP-A on the vhf oscillator board.

(6) Measure the frequency. If it is not within the initial tolerance given in chapter 3, adjust C204 and C206 for maximum output and exact frequency.

(7) Enter the required crystal oscillator measurements on FAA form 6620-1. *

(8) Disconnect the test equipment, and restore the receiver to service.

254. AUTOMATIC VOLUME CONTROL (AVC) ACTION.

a. **Object.** To determine the automatic volume control (avc) threshold and the effectiveness of the avc circuit in maintaining a constant receiver output level under wide variations of rf signal input.

b. **Discussion.** The avc feature is required to maintain a nearly constant audio output from the receiver for wide ranges of rf signal input that the receiver may be subject to, thereby eliminating the need for constantly readjusting the manual volume control.

c. **Test Equipment Required.**

(1) Rf signal generator or CSM.

(2) Audio power level meter or receiver test set.

d. **Conditions.** Adjacent receivers must be protected from high-level rf signals. Do not allow rf test signals to radiate longer than necessary to make the test. Limit rf generator output to 50,000μV (-13dBm). *

e. **Procedure, AVC Threshold.**

(1) Increase the signal generator or CSM output while observing the audio output level for the point at which avc throttling action starts. This is the point where the output ceases to increase in direct proportion to the input.

(2) AVC threshold is the rf test voltage input at which avc threshold occurs.

f. **Procedure, AVC Level Control.**

(1) Increase the signal generator or CSM output for an rf test voltage input to the receiver of 50μV.

(2) Adjust the af gain control for a receiver output of 50mW.

(3) For solid-state recievers, sweep the receiver input with rf test voltages from 3μV to 50,000μV. Note the corresponding receiver maximum and minimum power output levels for each step.

(4) Determine the difference of maximum to minimum receiver power output expressed in dB. *

g. **Detailed Procedure for Type WR-100 Receivers.** A complete test procedure is located in paragraph 4.3.3 of the Wulfsberg installation-operation manual.

255.-259. RESERVED.

Subsection 3. ANTENNAS AND TRANSMISSION LINES

260. MEASURING TRANSMISSION LINE LOSS.

a. Object. To measure the loss of a coaxial transmission line between transmitter output and antenna input.

b. Discussion.

(1) Loss in a coaxial cable transmission line is a function of the physical construction of the cable and the radio frequency in use. The presence of standing waves on a line add to the basic cable loss. Figure 13 in appendix 8 provides swr losses that may be used to derive total cable loss. The values on the horizontal axis represent the flat line losses of the particular cable from figure 14 in appendix 8. From this figure, determine the loss of the cable under consideration, and locate the value on the horizontal axis of the graph of figure 13, appendix 8. The swr loss that must be added to this value may be determined by following the vertical line that connects this point with the insertion of the appropriate swr curve (load end). Then read horizontally to the left edge of the graph where the additional losses are indicated in dB. Line losses for a discrete frequency can be estimated by considering that the attenuation varies (approximately) as the square root of the frequency ratio and is directly proportional to the length of the line.

EXAMPLE:

For RG-213/U at 100MHz, attenuation is 2.0dB per hundred feet. Therefore, attenuation at 125MHz is:

$$2.0 \ \mathrm{X} \ \sqrt{\frac{125}{100}} \cong 2.24\text{dB per hundred feet}$$

(2) With an in-line directional wattmeter connected at the sending end of the line that is terminated in a 50-ohm dummy load and rf power applied, a check of forward and reflected power may indicate an unsatisfactory line impedance if the reflected power is 5 percent or more of the forward power. Under these conditions, the transmission line may have deteriorated and should be replaced.

c. Test Equipment Required.

(1) Directional wattmeter set.

(2) Dummy load.

d. Conditions. Transmission line loss measurement requires disconnecting the line from the antenna. Therefore, shutdown coordination shall be accomplished with the air traffic (AT) watch supervisor in advance.

e. Detailed Procedure. See figure 5-10.

(1) Coordinate the channel shutdown with the AT watch supervisor.

(2) Deenergize the transmitter keying circuit, and disconnect the coaxial transmission line from the antenna input connector.

(3) Connect an in-line rf body of a directional wattmeter set in series in the line, and connect a dummy load of the proper impedance and power rating at the output of the rf body to act as a termination.

(4) Insert a directional element of the proper power rating in the forward power position in the rf body.

(5) Energize the transmitter, and read and record forward power at the antenna end of the transmission line. Read forward power at the sending end of the line, using the same rf body and wattmeter at the transmitter facility that was used at the antenna end.

(6) Deenergize the transmitter. Compute the line loss as follows.

$$\text{dB (loss)} = 10\,\mathrm{Log}_{10}\ \frac{\text{P (transmitter end)}}{\text{P (Antenna end)}}$$

NOTE: This test arrangement cannot be used for swr measurement at the antenna. The antenna must be reconnected as a load for the swr check. However, the swr and line loss checks can be accomplished at the same time to avoid the need to schedule an additional shutdown of the channel.

(7) If line loss is within tolerance, remove the rf body and dummy load, and reconnect the antenna. Proceed to check other lines terminating on the same antenna tower that are scheduled for the check.

261. MEASURING SWR ON COAXIAL TRANSMISSION LINES.

a. Object. To measure the swr on coaxial transmission lines at the load (antenna input).

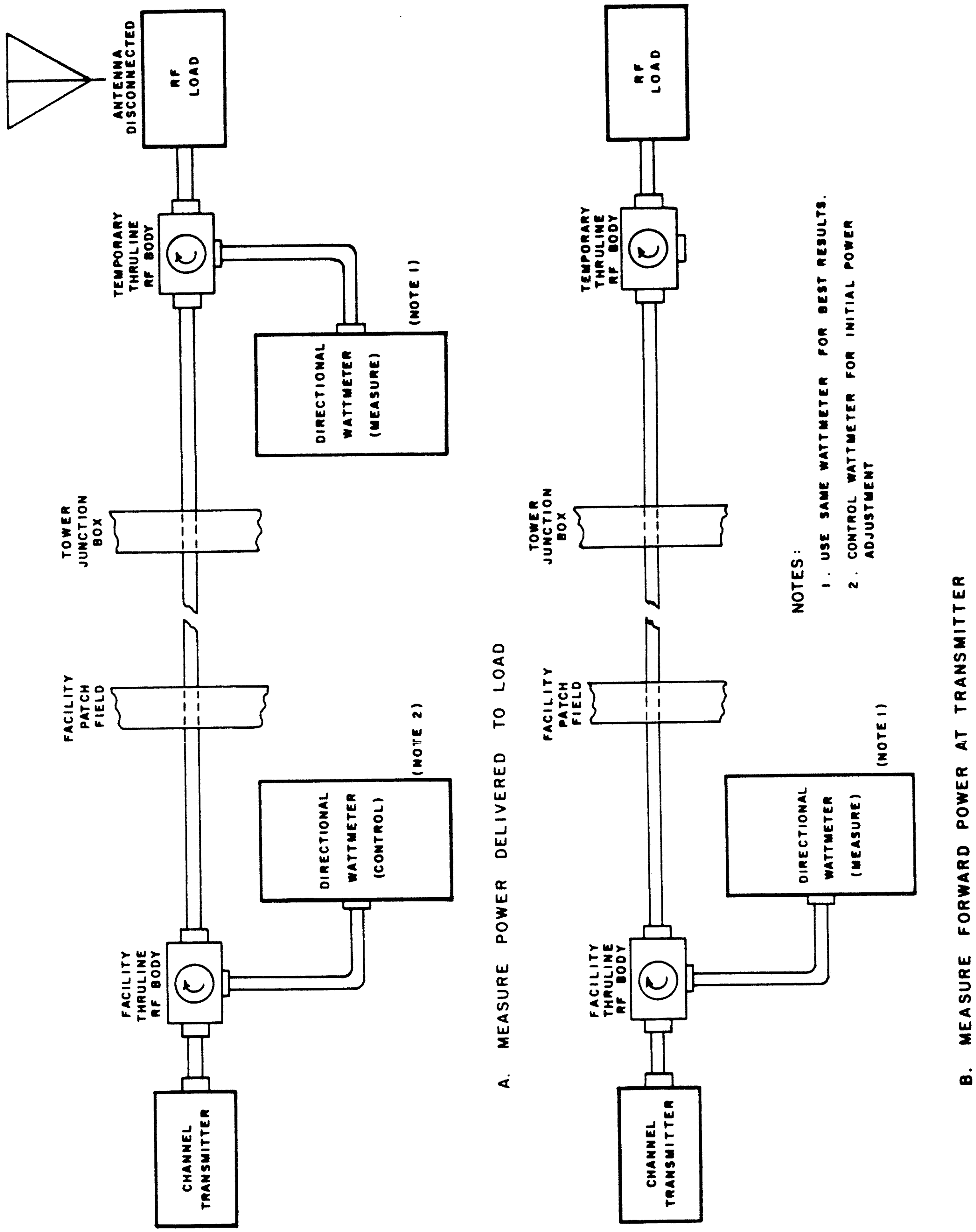


Figure 5-10. Measuring Coaxial Transmission Line Loss

b. Discussion. The swr is not constant along a transmission line, but is greatest at the load (antenna) end. For this reason, it is necessary to make the principal swr check of the antenna system at the antenna terminal of the line. The term "at the antenna" as used herein means at the antenna connector or at any transmission line connector that is accessible and that lies within 30 feet (10m) of the antenna. Swr readings at the rf bodies of the directional wattmeters at the transmitter output are related readings only. Those readings do not indicate swr unless the transmission line from transmitter to load is 30 feet (10m) or less. Swr of communication transmission cables may be checked with a slotted line. However, unless it is necessary to adjust the swr with a coaxial stub, the precision afforded by the slotted line is not needed. Slotted line stubbing procedures are not included in this order.

c. Test Equipment Required. Directional wattmeter with directional detectors.

d. Conditions. When necessary to shut down the channel for the required check, prior coordination with the AT watch supervisor is mandatory.

e. Detailed Procedure. Refer to the test arrangement of figure 5-11.

(1) Coordinate with the AT watch supervisor, and remove the channel transmitter from service.

(2) Disconnect the transmission line from the antenna connector and insert the directional wattmeter rf body between the line and antenna.

(3) Install a directional element in the forward power position in the rf body. Ensure that the element with proper power rating is installed.

(4) Energize the transmitter, and read and record the forward power indicated on the wattmeter.

CAUTION: Before the larger power element is removed, determine, by reversing the direction of this element to read reflected power, that the magnitude of reflected power does not exceed the power rating of the element used in step (5). If swr has become large, sufficient reflected power may damage the low-power element.

(5) Deenergize the transmitter, and install a directional element with lower power rating in the reverse or reflected power position in the directional wattmeter.

(6) Energize the transmitter, and read and record the reflected power indicated on the wattmeter. If insufficient deflection of the meter is obtained, deenergize the transmitter, and insert an element with lower power rating, after first determining (see the CAUTION above) that the lower-powered element will not be damaged.

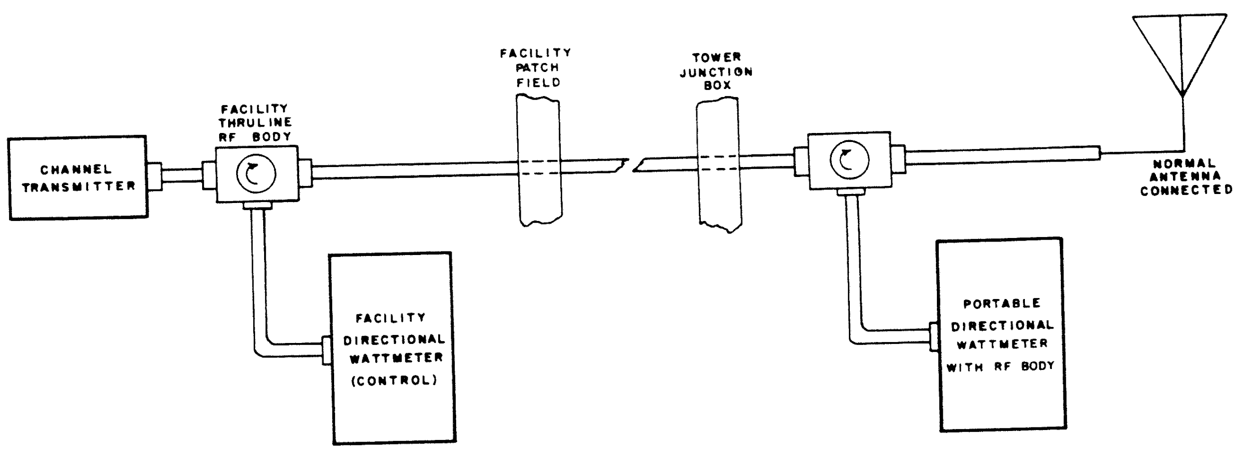


Figure 5-11. Measuring SWR at the Antenna

(7) Compute the swr from the recorded values of forward and reflected power by use of the applicable formula in appendix 8. The swr versus power curves in the directional wattmeter instruction book can also be used, as can figure 3, appendix 8.

(8) If the swr is within the tolerance allowed in chapter 3, reconnect the line to the antenna, and continue swr checks on other transmission lines on the tower.

262. MEASURING SWR ON OPEN-WIRE TRANSMISSION LINES.

a. **Object.** To measure swr on open-wire feeders.

b. **Discussion.** Directional couplers are generally impracticable for open-wire lines of pole-line construction. It is necessary to move a standing-wave detector over the line and observe meter maxima and minima, which are then converted by a simple computation to standing-wave ratio. A movable meter known as a trolley meter is used for this purpose. The portion of the line on which the meter is used is normally a horizontal section between the matching stub closest to the transmitter building and the transmitter output.

c. **Test Equipment Required.** Trolley meter, type CA-543A or equal.

d. **Condition.** High transmitter power cannot be used when this check is made. The transmitter is shut down following prior coordination with the AT watch supervisor. A low-power oscillator or low-power stage of the transmitter is loosely coupled at the coupling of the transmission line to the transmitting equipment. Just enough power should be used to obtain a maximum trolley meter deflection of about two-thirds the full-scale meter reading.

e. **Detailed Procedure.**

(1) Refer to figure 5-12 for a sketch showing a trolley meter in use on an open-wire feeder.

(2) With the draw cord and sufficient low power applied to the line, slow-draw the trolley meter (after peaking its meter coupling circuit to maximum) from a position near the correcting stub toward the transmitter building.

(3) When the meter pointer reaches a maximum value, goes through it, and then reaches a minimum, record these maximum and minimum values. Repeat procedure by towing the meter backward toward the stub, reconfirming the maximum and minimum readings on the meter.

(4) If the trolley meter is a square-law type, compute the swr by using the applicable formula of appendix 8 and the readings of step (3).

(5) If the trolley meter is of the non-square-law type, there will be a chart on the meter box or in the trolley meter instruction manual by which the meter deflections are converted for use in the same formula.

(6) An excessive swr indicates matching is incorrect. The correcting stub may have to be repositioned and/or lengthened or shortened to obtain a sufficiently low swr on the line.

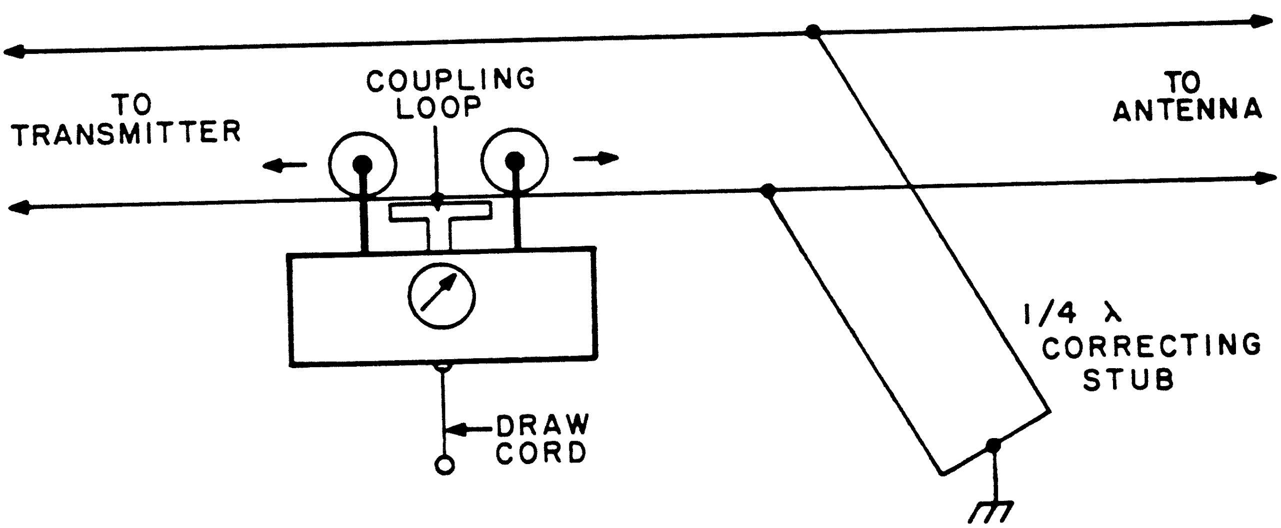


Figure 5-12. Measuring Open-Wire Line SWR

NOTE: Before moving or otherwise changing the dimensions of the stub, check the condition of the transmission line, and recheck trolley meter readings. A standing-wave ratio that suddenly changes is a likely indication of damage to the line or improper technique in use of the trolley meter.

(7) Following all required procedure steps, remove the low-power line excitation, and restore the equipment and antenna system to service.

263. RECEIVING ANTENNA AND TRANSMISSION LINE TESTS.

At most a-g vhf and uhf facilities, the same transmission line type or types are used for receiving as are used for transmitting. Therefore, performance tests and other maintenance tasks applicable to the transmitting line are equally applicable to the receiving line. When receiving facilities are separate from transmitting facilities, use a movable low-power transmitter or portable transceiver to energize the receiving line for tests. In so doing, observe the necessary precaution to prevent interfering with receiving equipment. Prior coordination with AT operations in mandatory.

264.-269. RESERVED.

Section 2. OTHER MAINTENANCE TASKS PROCEDURES

Subsection 1. Transmitters

270. GENERAL.

Refinements in tuning and neutralization are to be accomplished periodically in asccordance with chapter 4 schedules.

271.-279. RESERVED.

Subsection 2. RECEIVERS

280.-289. RESERVED.

Subsection 3. ANTENNAS AND TRANSMISSION LINES

290. MEASURING INSULATION RESISTANCE OF ANTENNAS.

With a 500-volt insulation tester, measure the insulation resistance of the antenna from the accessible connector nearest the antenna (minimum length of cable between the insulation tester and the antenna). Antennas with internal shorted stubs or capacitive coupling are exempted from this procedure. If the insulation resistance has fallen below the tolerance specified in chapter 3, the cause of the low resistance reading should be determined and corrected. the cable and connectors should not be overlooked during investigation of the antenna even though the cable length may be only a few feet. The usual cause of low antenna insulation resistance is moisture absorption by the insulators and input receptacles or a coating of dirt, ice, and/or moisture on the surface of the insulators. Cleaning of the insulators is a required step toward restoring the insulating resistance to within tolerance. For information purposes, a check of swr should be conducted before and after cleaning the insulators.

291. MEASURING INSULATION RESISTANCE OF TRANSMISSION LINES.

Using a 500-volt insulation tester, measure the insulation resistance of the transmission line (at the transmitter or receive end) with the line connected to its associated antenna. If the measured value of insulation resistance is less than 3 megohms, investigative action is needed. Disconnect the transmission line from the antenna, and check the insulation resistance of the transmission line alone. If the measured resistance is less than 3 megohms, corrective action is required. The cause for low values of insulation resistance should be traced and corrected. Rf cable connectors are usually a source of leakage (due to presence of moisture) unless well protected from the weather. If moisture is present, remove the connectors from the cable, and thoroughly dry or replace them with new connectors. If the insulation resistance still reads less than 3 megohms after removal of the connectors, the trouble may be due to cold-flow migration of the center conductor to the shield or contamination of the cable dielectric caused by migration of the vinyl jacket through the shield. Since the latter condition is usually not apparent from a visual inspection, check the line characteristic impedance. See also paragraphs 53 and 54, Order 6950.22, Maintenance of Electrical Power and Control Cables.

292. MEASURING DC SERIES RESISTANCE.
Using a shorted connector or clip lead to short the antenna, measure the center conductor to outer shield loop resistance with a volt-ohm milliammeter (vom) at the equipment end of the line. For TACO 2200 series antenna systems, disconnect the line at the antenna, and measure the resistance of the line only. This can be accomplished by using a shorted connector or clip lead to short the line and measuring the center conductor to outer shield loop resistance with a vom. Record the value in ohms for comparisons with facility records. See also paragraph 54 of Order 6950.22.

293. ALTERNATIVE CHECKS FOR SHORTED-STUB, BALUN-INPUT, TACO, OR DHV ANTENNAS.

The construction of certain vertical antennas, particularly the shorted-stub types, balun-input types, TACO, and DHV high-performance, vertical, single-dipole, and multielement types makes impossible routine insulation resistance measurement of the lines only in accordance with paragraph 101e. The condition of the antennas should be ascertained by applying the swr check of paragraph 261 at the antenna input at the frequency of operation assigned to the particular antenna. For the TACO and DHV antennas, the swr versus frequency curves of figure 2-40 can be used to compare the swr as measured. For other antennas for which curves are not published, swr versus frequency curves can be measured locally and plotted for retention in station files. Prior to all measurements, antenna insulating elements and hardware, including connectors, should be cleaned and free of accumulated grime and grease.

294.-299. RESERVED.

Section 3. SPECIAL MAINTENANCE PROCEDURES

300. TIME-DOMAIN REFLECTOMETER TESTS ON TRANSMISSION LINES.

a. The time-domain reflectometer (TDR) is a portable, battery-powered oscilloscope instrument for the evaluation of discontinuities in 50-ohm transmission lines. It transmits a fast-rise pulse of 140 picoseconds (ps) or less and displays the reflection component. Anomalies in the reflection displayed on the cathode-ray tube (crt) of the instrument or recorded on the thermal paper tape indicates discontinuities such as crimps, breaks, shorts, cold-flow, and other problems in the transmission line. The calibrated time base of the crt permits locating a fault with resolution depending on the range time base used. The model 1502 has a range of up to 2000 feet (500 meters). (A metric range model 1502 is an option.) A short-range model is under current procurement for evaluation of the relatively short-run cable round at vhf and uhf communication transmitter and receiver sites, and at navigational and landing aids facilities.

b. A valuable feature of the recording option is the cable signature run that should be conducted at the time new cable is installed or when cable that is known to be good is checked. Kept on file, the recorded pattern is useful for future signature comparisons as the cable ages or a fault, such as cold-flow, is suspected to have developed.

c. Complete operating instructions are contained in the instruction manual, Tektronix 1502 Time Domain Reflectometer, Tektronix, Inc., P.O. Box 500, Beaverton, Oregon 97077. Included in the manual are illustrations showing typical crt displays for the most common cable faults.

301. TESTING FOR STRAY COAXIAL LINE RADIATION.
Coaxial cable, when properly installed, energized, and loaded, should have no rf radiation along its length. The presence of stray radiation is an indication of some kind of fault. Stray radiation will interfere with nearby services and cause inefficient operation of the antenna system associated with the cable. Detection of radiation is accomplished with a wavemeter or grid-dip meter, the probe of which is passed along the length of the cable (within the facility) and observed for a meter deflection. A broadly responsive instrument may require shutting off all other equipment except that energizing the line under test. Some defects that result in stray radiation are: corroded and tarnished braid, defective coaxial a. Connectors and connections, mismatched lines and loads, and excessive power for the cable type in use.

302. OPEN-WIRE TRANSMISSION LINE BALANCE.

a. **Object.** To check the balance of rf current in open-wire balanced feeders.

b. **Discussion.** When rf ammeters are insert at identical points in each side of a balanced transmission line, the relationship between the two readings indicates the state of balance in the line. When a transmission line is

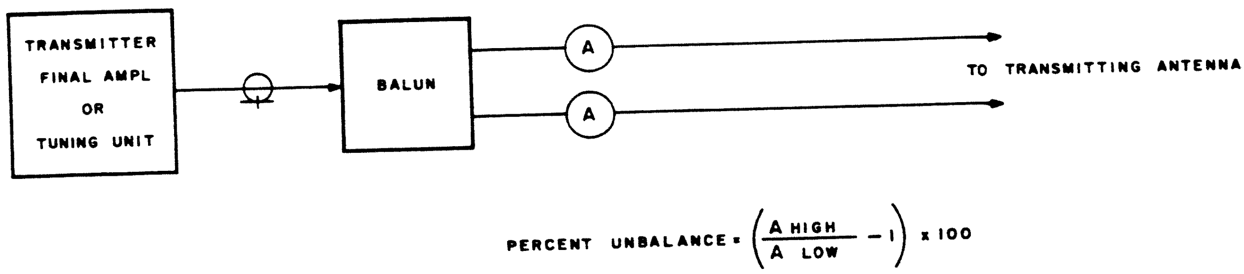


Figure. 5-13. Measuring Open-Wire Line Balance

perfectly balanced, there is a minimum of radiation from the line itself. Therefore, if the meter readings show more than a 10 percent difference, the line should be readjusted for proper balance. When balanced lines are used in unsymmetrical antenna systems, such as an end-fed half-wave antenna, a difference in the readings of the two sides of the line indicates that the antenna is of improper length.

c. **Test Equipment Required.** Two rf ammeters, range or scale calibration adequate for current expected in the transmission line (each side).

d. **Conditions.** If the rf ammeters are permanently mounted in the transmission line, usually no shutdown will be needed. If a shutdown is needed to insert the ammeters in series with the sides of the line, prior coordination with the AT watch supervisor is mandatory.

e. **Detailed Procedure.**

(1) Shut down the transmitter, and ensure that all high voltage is removed by testing with a shorting stick after opening the main high-voltage contactor on the transmitter final amplifier power supply.

(2) Connect each rf ammeter in series with one side of the transmission line as close to the transmitter output as possible. If a balun is used to convert an unbalanced transmitter output to balanced, connect the ammeters at the balanced output terminals or in each side of the line near the balun output. See figure 5-13.

(3) Energize the transmitter, and adjust for normal operation.

(4) Record the readings of the ammeters. The readings should differ by no more than 10 percent.

(5) If in tolerance, shut down the transmitter, remove the ammeters, reconnect the transmission line, and restore normal transmitter operation.

NOTE: Open-wire balance can be determined with a trolley meter. However, series-connected rf ammeters are much more convenient to use.

303. RADIATION PATTERN GROUND CHECK.

A ground check of a-g communication antennas is not normally an effective procedure. The angle of radiation (skywave) is above the terrain and not ordinarily measurable on the ground. However, the use of vehicular-mounted transceivers capable of receiving discrete a-g frequencies may provide reference data to determine system deterioration. The ground check is made with a procedure very much like that in Order 6530.3D, Maintenance of Direction Finder (DF) Equipment. Checkpoints are established at places marked on maps of the communication facility area where transmitters and receivers are installed. If reliable two-way contact can be made from 10 to 40 miles (16m to 64m) from the facility and can be repeated, the facility can be said to be operating satisfactorily. The best check is reliable two-way aircraft contact which is made via routine AT operation many times a day. It would be under exceptional circumstances that a ground check would be required or be of any great benefit.

304. SWR LOSS CHECK OF OLD COAXIAL TRANSMISSION LINES.

a. Object. To evaluate swr loss on old coaxial transmission lines.

b. Discussion. Coaxial lines that have been in use for several years may have deteriorated so much that their losses have increased above the unit-length values published for the type of cable. Such cable will decrease effective radiated power, especially for low-power (10 watts or less) transmitters. It is essential that these older cables be checked between the third and fifth year of use. They should be replaced if the test results are poor. No test equipment is required at antenna end of the line.

c. Test Equipment Required.

(1) Directional wattmeter set.

(2) Short-circuit connector termination.

d. Conditions. The coaxial cable must be temporarily removed from service and a spare cable (or antenna with cable) substituted. A short shutdown of the channel may be required; the AT watch supervisor should be contacted for permission to exchange antennas and lines.

e. Detailed Procedure.

(1) Remove from service the cable to be tested. Substitute either a spare cable for the assigned antenna or a complete antenna and transmission line system on the channel affected.

(2) Disconnect the cable at the antenna end from the antenna input connector. Short-circuit the cable at the antenna end by substituting a shorted receptacle connector of the type used at the antenna input.

(3) With the directional wattmeter connected at the driven end, as in figure 5-14, part A, supply low power to the line at the frequency of use and measure the forward and reflected power.

(4) Compute the swr on the line (see appendix 8) and, using the chart of figure 5-14, part B, determine the total loss of the transmission line when perfectly terminated. If this loss exceeds by 5 percent the published loss of that type of cable per unit length, replace the entire length of transmission line.

305.-314. RESERVED.

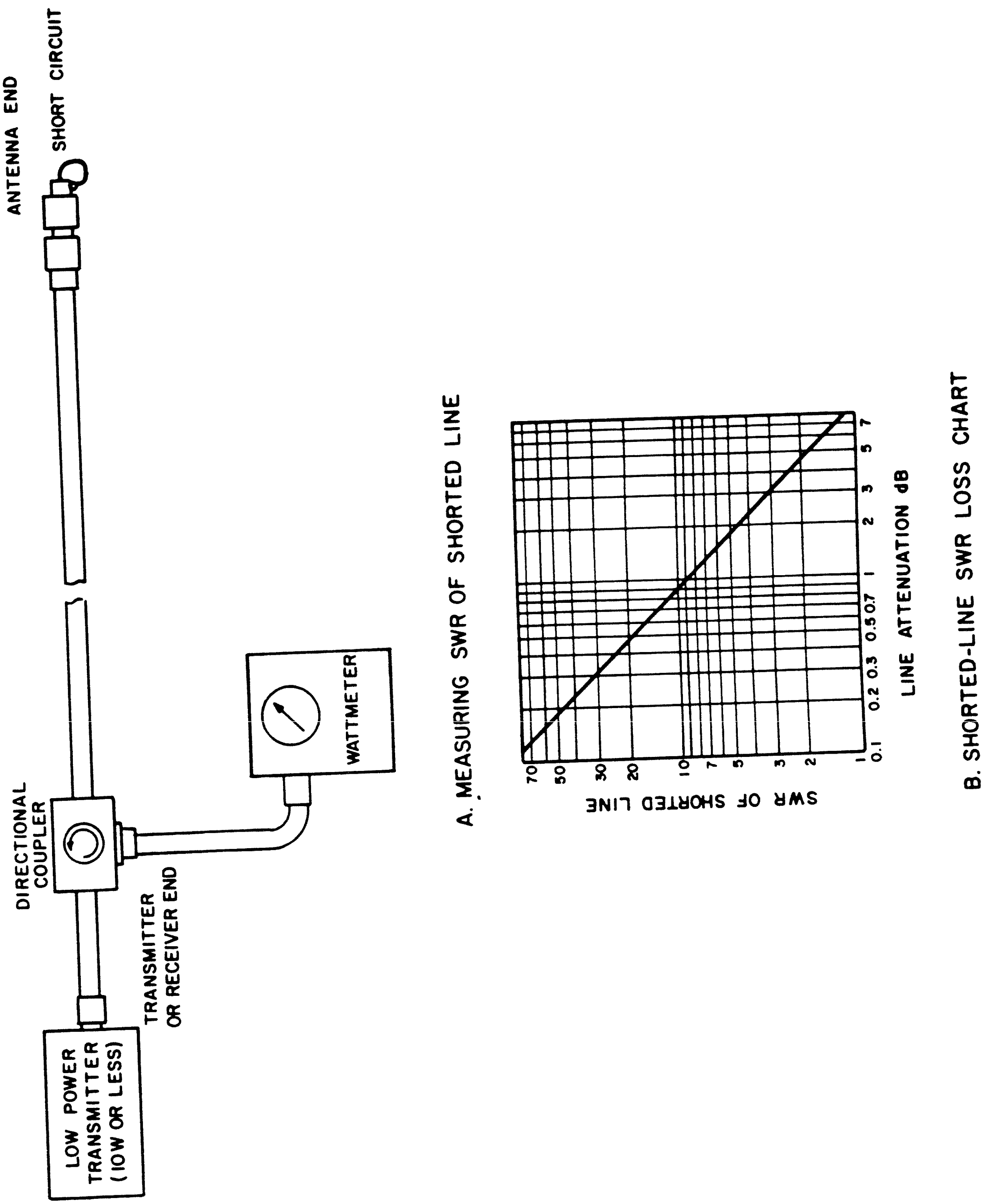


Figure 5-14. SWR Loss Test of Old Coaxial Cable

CHAPTER 6. FLIGHT INSPECTION

315. GENERAL.

Flight inspections are made to verify the overall performance of an air-ground (a-g) communication facility. The instructions for flight inspection are contained in OA P 8200.1, United States Standard Flight Inspection Manual. Flight inspections are required as specified in the flight inspection manual and when requested by regional authority. Ground-to-air (g-a) communications, such as VOLMET and other voice broadcast communications, are flight checked by normal aircraft contact. Pilot reports (pirep's) concerning deficiencies in coverage and intelligibility are filed and responded to by Airway Facilities divisions. Point-to-point (PTP) circuits operating as fixed stations are not flight checked.

316. ACTIVITIES THAT MAY REQUIRE A CONFIRMING FLIGHT INSPECTION.

Flight inspections of commissioned communication facilities are normally accomplished in conjunction with other primary navigational aids. The expense of a special trip or priority flight inspection is not warranted in most situations if sufficient targets of opportunity are available on which to make a decision. (Detailed policy is outlined in OA P 8200.1.) The following activities should be considered as candidates for requesting a confirming flight inspection:

a. Major changes in location obstructions or buildings that may affect the signal strength or coverage.

b. Change in transmitter rf output level for the purpose of increasing or decreasing service area.

c. Frequency changes.

d. Replacement, relocation, or reorientation of antennas.

317. ACTIVITIES NOT REQUIRING A CONFIRMING FLIGHT INSPECTION.

The following may be accomplished by electronic maintenance technicians without recourse to flight inspection:

a. Replace or repair transmitter components.

b. Retune all stages of the transmitter.

c. Measure and adjust voice modulation percentages to values established during flight inspection.

d. Accomplish other maintenance procedures, provided the conditions are restored to those that existed at the time of the last flight inspection as reflected in the current FAA forms 6600-6, 6610-1, or 6620-1.

318.-324. RESERVED.

CHAPTER 7. MISCELLANEOUS

325. GENERAL.

This chapter contains miscellaneous information and guidance concerning communication antennas and transmission lines.

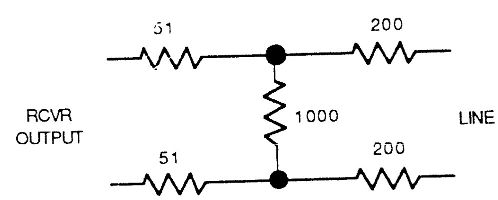
326. EXPANSION AND CONTRACTION.

The coefficient of expansion of the center conductor of a coaxial cable is greater than that of the dielectric. With long transmission lines and wide temperature variations, this difference in expansion results in a considerable degree of slippage of the center contact pin of the coaxial connectors. During cold weather conditions, the technician should be alert for open transmission line connections. To ensure electrical continuity as coaxial cable expands and contracts with temperature changes, UG-495A and WHC-321-1 connectors with telescoping pin contacts should be provided or should be replaced with captivated connectors. Foamflex or Styro-66 type cable is not subject to expansion, contraction, or cold-flow problems.

327. INTERFACING AN/GRR-23 AND AN/GRR-24 TYPE RECEIVERS TO TELCO EQUIPMENT.

a. The audio output impedance of the AN/GRR-23 and AN/GRR-24 receivers is approximately 150 ohms. A mismatch will occur where receivers interface to telco equipment whose characteristic impedance is 600 ohms. Ample receiver gain is available to overcome signal loss; however, poor audio quality and high signal-to-noise ratios will result.

b. The impedance looking back into the receiver output should be measured. If the impedance is significantly less than 600 ohms (such as 450 ohms), a balanced H-pad should be installed between the receiver output and the telco line. Figure 7-1 shows such a pad with resistor values and national stock numbers (NSN).



Note: Resistor NSN's are:

51-ohm	5905-00-114-5438
200-ohm	5905-00-141-0727
1000-ohm	5905-00-110-0196

Figure 7-1. Solid-State Receiver Interface Pad

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APPENDIX 1. GLOSSARY

Absorption Loss. That part of the transmission loss due to the dissipation or conversion of electrical energy into other forms of energy (e.g., heat), either within the medium or attendant upon a reflection.

Air Mobile. Communication between a fixed base station located on the ground, and aircraft, or between an aircraft and other aircraft.

Antenna. A means of radiating or receiving radio waves.

Antenna Array. A system of antennas coupled together for the purpose of obtaining directional gain effects.

Antenna Resistance. The quotient of the power supplied to the entire antenna circuit by the square of the effective antenna current referred to a specified point. Antenna resistance consists of such components as radiation resistance, ground resistance, radio-frequency resistance of conductors in the antenna circuit, and equivalent resistance due to corona, eddy currents, insulator leakage, and dielectric power loss.

Aperture (of a unidirectional antenna). That portion of a plane surface near the antenna, perpendicular to the direction of maximum radiation, through which the major part of the radiation passes.

Atmospheric Duct. An almost horizontal layer in the troposphere, extending from the level of a local minimum of the modified refractive index as a function of height, down to a level where the minimum value is again encountered, or down to the earth's surface if the minimum value is not again encountered.

Attenuation. Of a quantity associated with a traveling wave in a homogeneous medium, the decrease with distance in the direction of propagation.

Attenuation Constant. For a traveling plane wave at a given frequency, the rate of exponential decrease of the amplitude of a field component (or of the voltage or current) in the direction of the propagation, in nepers or decibels per unit length.

Bandwidth (of a device). The range of frequencies within which performance, with respect to some characteristic, falls within specific limits.

Bandwidth (of a wave). The least frequency interval outside of which the power spectrum of a time-varying quantity is everywhere less than some specified fraction of its value at a reference frequency. Unless otherwise stated, the reference frequency is that at which the spectrum has its maximum value.

Bolometer. A specially constructed resistor which has a positive temperature coefficient and which is used for power measurements.

Carrier Wave. A wave generated at a point in the transmitting system and modulated by the signal.

Characteristic Impedance (Z_o). The ratio of the voltage to the current at every point along a transmission line on which there are no standing waves.

Coefficient of Reflection. The square root of the ratio of the reflected power leaving a reflecting surface to the power incident to the same surface.

Conduction Current. The power flow parallel to the direction of propagation expressed in watts per square meter.

Conductivity. A measure of the ability of a material to act as a path for electron flow. It is the reciprocal of resistivity and is expressed in mhos/meter.

Critical Frequency. The limiting frequency below which a magnetoionic wave component is reflected by, and above which it penetrates through, an ionospheric layer at vertical incidence.

Cross Modulation. Modulation of a desired signal by an undesired signal.

Dewpoint. The temperature at which the water vapor in the air begins to condense.

Diffraction. The bending of a wave into the region behind an obstacle.

Dipole Antenna. A straight radiator, usually fed in the center, and producing a maximum of radiation in the plane normal to its axis. The length specified is the overall length.

Direct Wave. A wave that is propagated directly through space.

Direction of Propagation. At any point in a homogeneous, isotropic medium, the direction of time average energy flow.

Directional Antenna. An antenna having the property of radiating or receiving radio waves more effectively in some directions than others.

Directive Gain. In a given direction, 4π times the ratio of the radiation intensity in that direction to the total power radiated by the antenna.

Directivity (of an antenna). The ratio of maximum radiation intensity to the average radiation intensity. (In a theoretical antenna that is 100 percent efficient and with no losses, directivity and gain are the same.)

Displacement Current. The current at right angles to the direction of propagation determined by the rate at which the field energy changes.

Distortion. An undesired change in wave form.

Effective Area. The square of the wavelength multiplied by the power gain (or directive gain) in that direction, and divided by 4π.

NOTE: When power gain is used, the effective area is that for power reception; when directive gain is used, the effective area is that for directivity.

Effective Radius of the Earth. An effective value for the radius of the earth, which is used in place of the geometrical radius to correct for atmospheric refraction when the index of refraction in the atmosphere changes linearly with height. Under conditions of standard refraction the effective radius of the earth is 8.5×10^6 meters, or 4/3 the geometrical radius.

Electric Field Strength. The magnitude of the electric field vector.

Electric Field Vector. At a point in an electric field, the force on a stationary positive charge per unit charge. This may be measured either in newtons per coulomb or in volts per meter. This term is sometimes called the electric field intensity but such use of the word intensity is deprecated in favor of field strength since intensity connotes power in optics and radiation.

Elliptically Polarized Wave. An electromagnetic wave for which the electric and/or the magnetic field vector at a point describes an ellipse. This term is usually applied to transverse waves.

Fading. The variation of radio field strength caused by changes in the transmission medium with time.

Fraunhofer Region. That region of the field in which the energy flow from an antenna proceeds essentially as though coming from a point source located near the antenna. If the antenna has a well-defined aperture D in a given aspect, the Fraunhofer region in that aspect is commonly taken to exist at distances greater than $2D^2/\lambda$ from the aperture, λ being the wavelength.

Fresnel Region. The region between the antenna and the Fraunhofer region. If the antenna has a well-defined aperture D in a given aspect, the Fresnel region in that aspect is commonly taken to extend a distance $2D^2/\lambda$ in that aspect, λ being the wavelength.

Fresnel Zones. Zones of wave reinforcement and destructive interference caused by interaction of direct waves and those waves reflected from the earth.

Gain (of an antenna). The ratio of the maximum radiation intensity in a given direction to the maximum radiation intensity produced in the same direction from a reference antenna with the same power input. (In communication and television, the reference antenna is usually the half-wave dipole; whereas, in microwave applications, an isotropic source is usually the reference antenna.)

Ground Mobile. Communication between a fixed base station located on the ground and ground vehicles, or between a ground vehicle and other ground vehicles.

Groundwave. A radio wave that is propagated over the earth and is ordinarily affected by the presence of the ground and the troposphere. The groundwave includes all components of a radio wave over the earth except ionospheric and tropospheric waves.

NOTE: The groundwave is refracted because of variations in the dielectric constant of the troposphere including the condition known as *surface duct.*

Group Velocity. Of a traveling plane wave, the velocity of propagation of the envelope of a wave occupying a frequency band over which the envelope delay is approximately constant. It is equal to the reciprocal of the rate of change of phase constant with angular frequency. Group velocity differs from phase velocity in a medium in which the phase velocity varies with frequency.

Half-Power Width of a Radiation Lobe. In a plane containing the direction of the maximum of the lobe, the full angle between the two directions in that plane about the maximum in which the radiation intensity is one-half the maximum value of the lobe.

Harmonic. A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency. For example, a component the frequency of which is twice the fundamental frequency is called the second harmonic.

Heterodyne. To beat or mix two frequencies in a nonlinear component so as to produce different frequencies from those introduced.

Horizontally Polarized Wave. A linearly polarized wave whose electric field vector is horizontal.

Incident Wave. In a medium of certain propagation characteristics, a wave that impinges on a discontinuity or medium of different propagation characteristics.

Interference. In a signal transmission system either extraneous power, which tends to interfere with the reception of the desired signals, or the disturbance of signals that results.

Ionosphere. The part of the earth's outer atmosphere where ions and electrons are present in quantities sufficient to affect the propagation of radio waves.

Isotropic Antenna (unipole). A hypothetical antenna radiating or receiving equally in all directions. A pulsating sphere is a unipole for sound waves. In the case of electromagnetic waves, unipoles do not exist physically but represent convenient reference antennas for expressing directive properties of actual antennas.

Kelvin Scale (absolute scale). A temperature scale using the same divisions as the centrigrade scale, but with the zero point established at absolute zero ($\cong -273°C$), theoretically the lowest possible temperature.

Leakage Radiation (stray radiation). In a transmitting system, radiation from anything other than the intended radiating system.

Linearly Polarized Wave. At a point in a homogeneous, isotropic medium, a transverse electromagnetic wave whose electric field vector at all times lies along a fixed line.

Lowest Useful High Frequency. The lowest high frequency effective at a specified time for ionospheric propagation of radio waves between two specified points.

NOTE: This is determined by factors such as absorption, transmitter power, antenna gain, receiver characteristics, type of service, and noise conditions.

Magnetic Field. A state of the medium in which moving electrified bodies are subject to forces by virtue of both their electrifications and motion.

Magnetoionic Wave Component. Either of the two elliptically polarized wave components into which a linearly polarized wave incident on the ionosphere is separated because of the earth's magnetic field.

Maximum Usable Frequency. The upper limit of the frequencies that can be used at a specified time for radio transmission between two points and involving propagation by reflection from the regular ionized layers of the ionosphere.

NOTE: Higher frequencies may be transmitted by sporadic and scattered reflections.

Modified Index of Refraction. In the troposphere, the index of refraction at any height increased by h/a, where h is the height above sea level and a is the mean geometrical radius of the earth. When the index of refraction in the troposphere is horizontally stratified, propagation over hypothetical flat earth through an atmosphere with the modified index of refraction is substantially equivalent to propagation over a curved earth through the real atmosphere.

Multipath Transmission. The propagation phenomenon that results in signals reaching the radio receiving antenna by two or more paths, usually having both amplitude and phase differences between each path.

Noise. Any extraneous electrical disturbance tending to interfere with the normal reception of a transmitted signal.

Optical Horizon. The locus of points at which a straight line from the given point becomes tangential to the earth's surface.

Optimum Working Frequency. The most effective frequency at a specified time for ionospheric propagation of radio waves between two specified points.

NOTE: In predictions of useful frequencies the optimum working frequency is commonly taken as 15 percent below the monthly median value of the maximum usable frequency, for the specified time and path.

Path Attenuation. The power loss between transmitter and receiver due to all causes. It is equal to 10 $\log_{10} P_t/P_r$ where P_t is the power radiated from the transmitting antenna and P_r is the power available at the output terminals of the receiving antenna. It is expressed in decibels.

Permeability. A measure of the ability of a material to act as a path for magnetic lines of force.

Phase Constant. For a traveling phase wave at a given frequency, the rate of linear increase of phase lag of a field component (for the voltage or current) in the direction of propagation, in radians per unit length.

Plane Velocity. Of a traveling plane wave at a single frequency, the velocity of an equiphase surface along the wave normal.

Plane Wave. A wave whose equiphase surfaces form a family of parallel planes.

Polar Diagrams. A system of coordinates in which a point is determined by the length and the angle of a line connecting the center of the diagram and the point.

Power Gain. In a given direction, 4π times the ratio of the radiation intensity in that direction to the total power delivered to the antenna.

Propagation Constant. For a traveling plane wave at a given frequency, the complex quantity whose real part is the attenuation constant in nepers per unit length and whose imaginary part is the phase constant in radians per unit length.

Radiation Efficiency. The ratio of the power radiated to the total power supplied to the antenna at a given frequency.

Radiation Intensity. In a given direction, the power radiated from an antenna per unit solid angle in that direction.

Radiation Resistance. The quotient of the power radiated by an antenna divided by the square of the antenna current referred to a specific point.

Radio Horizon. The locus of points at which direct rays from the transmitter become tangential to the earth's surface.

NOTE: On a spherical surface the horizon is a circle. The distance to the horizon is affected by atmospheric refraction.

Reflection. The phenomenon that causes a wave which strikes a medium of different characteristics to be returned into the original medium with the angles of incidence and of reflection equal and lying in the same plane.

Refraction. The phenomenon that causes a wave which enters another medium obliquely to undergo an abrupt change in direction if the velocity of the wave in the second medium is different from that in the first.

Refracted Wave. The part of an incident wave that travels from one medium into a second medium.

Refractive Index. Of a wave transmission medium, the ratio of the phase velocity in free space to that in the medium.

Scattering. When radio waves encounter matter, a disordered change in the direction of propagation of the waves.

Selective Fading. Fading in which the variation of radio field intensity is not the same at all frequencies in the frequency band of the received wave.

Signal-To-Noise Ratio. The ratio in decibels of the value of the signal to that of the noise. This ratio is usually in terms of peak values in the case of impulse noise and in terms of the root-mean-square values in the case of the random noise. Where there is a possibility of ambiguity, suitable definitions of the signal and noise should be associated with the term; for example, peak-signal to peak-noise ratio, root-mean-square signal to root-mean-square noise ratio, and peak-to-peak signal to peak-to-peak noise ratio.

Smith Chart. An impedance chart consisting of orthogonal families of circles. One family consists of constant resistance circles. The second family consists of constant reactance circles. Circles of constant vswr are concentric with the center of the chart. The point of zero reflection coefficient (vswr = 1) is at the center of the chart. The locus of unity reflection coefficient (vswr = infinity) is the limiting circle of the chart.

Spherical Wave. A wave whose equiphase surfaces form a family of concentric spheres.

Standard Refraction. The refraction that would occur in an idealized atmosphere in which the index of refraction decreases uniformly with height at a rate of 39×10^{-6} per kilometer.

NOTE: Standard refraction may be included in groundwave calculations by use of an effective earth radius of 8.5×10^6 meters, or 4/3 the geometrical radius of the earth.

Standing Wave. A wave in which, for any component of the field, the ratio of its instantaneous value at one point to that at any other point does not vary with time.

Surface Duct. An atmospheric duct for which the lower boundary is the surface of the earth.

Tenth-Power Width. In a plane containing the direction of the maximum of a lobe, the full angle between the two directions in that plane about the maximum in which the radiation intensity is one-tenth the maximum value of the lobe.

Thermistor. A specially constructed resistor that has a negative temperature coefficient; it is used for power measurements.

Transverse Electric Wave (TE Wave). In a homogenous isotropic medium, an electromagnetic wave in which the electric field vector is everywhere perpendicular to the direction of propagation.

Transverse Electromagnetic Wave (TEM Wave). In a homogenous isotropic medium, an electromagnetic wave in which both the electric and magnetic field vectors are everywhere perpendicular to the direction of propagation.

Transverse Magnetic Wave (TM Wave). In a homogeneous isotropic medium, an electromagnetic wave in which the magnetic field vector is everywhere perpendicular to the direction of propagation.

Traveling Plane Wave. A plane wave each of whose frequency components has an exponential variation of amplitude and a linear variation of phase in the direction of propagation.

Troposphere. That part of the earth's atmosphere in which temperature generally decreases with altitude, clouds form, and convection is active. The troposphere occupies the space above the earth's surface to a height of about 10 kilometers.

Tropospheric Wave. A radio wave that is propagated by reflection from a place of abrupt change in the dielectric constant or its gradient in the troposphere.

NOTE: In some cases the groundwave may be so altered that new components appear to arise from reflections in regions of rapidly changing dielectric constants. When those components are distinguishable from the other components, they are called tropospheric waves.

Vector. A quantity that has both magnitude and direction or an arrow drawn in the direction of, and whose length is proportional to, the magnitude of the quantity.

Vertically Polarized Wave. A linearly polarized wave whose magnetic field vector is horizontal.

Voltage Standing-Wave Ratio (VSWR) The voltage ratio expressing standing-wave ratio (rf on a transmission line). For example:

$$SWR_{dB} = 20 \log_{10} VSWR = 20 \log_{10} \frac{V_{max}}{V_{min}}$$

Waveguide. A system of material boundaries capable of guiding waves.

Wave Interference. The variation of wave amplitude with distance or time, caused by the superposition of two or more waves.

NOTE: As most commonly used, the term refers to the interference of waves of the same or nearly the same frequency.

Wavelength. In a periodic wave, the distance between points of corresponding phase of two consecutive cycles. The wavelength λ is related to the phase velocity, v, and the frequency, f, by $\lambda = v/f$.

APPENDIX 2. BASIC TESTS FOR TRANSMITTERS AND RECEIVERS

1. GENERAL.

a. This section discusses the basic tests to be used in checking the critical transmitting and receiving equipment performance parameters. The parameters, and their standard values, tolerances, or limits, are listed in chapter 3 of this order.

b. The transmitter tests are for rated power output, modulation percentage, spurious emissions, and crystal oscillator frequency stability. In single-sideband (ssb) transmitters, the internal sideband exciter and converter crystal-frequency stability is of utmost importance. Receiver tests include sensitivity in rf antenna voltage for a specified audio output, crystal oscillator frequency stability, and intermediate-frequency (if) amplifier selectivity and bandpass symmetry.

2. TRANSMITTER OUTPUT POWER.

a. **AM Transmitters.** The technique of measuring rated transmitter power (for example, am transmitter output power) depend ultimately upon the service employed and the federal regulations involving that type of service. For example, am or continuous wave (cw) transmitters used in amateur radio service are rated in plate input power for which the maximum allowed is stipulated by the Federal Communications Commission (FCC). For a measurement of this kind, it is necessary to measure only the key-down plate current to the loaded final amplifier tube and the dc plate voltage, then multiply the two to obtain the input power. For a precise indication of final amplifier output power, it is necessary to measure either the average transmission line current in a known antenna input impedance, or to use a directional rf wattmeter in a coaxial transmission line. In FAA vhf and uhf applications, it is a universal practice to use the directional wattmeter in the coaxial line to determine both the standing-wave ratio (swr) and the transmitter output power. Most vhf and uhf transmitters used in FAA are class C amplifiers having a relatively efficient (up to 70 percent) output stage. The linear am transmitter amplifier, which sometimes follows a high-level-modulated class C amplifier, will operate in a mode between class A and class B, (AB1 or AB2) and is of lesser efficiency than the class C amplifier. The linear amplifier power is best determined, for an unbalanced output, by the directional wattmeter. For a balanced output, by using rf ammeters in series in each side of the transmission line, the I^2Z_o relationship provides the measure of average power. The wattmeter is installed in the transmission line near the output of the transmitter. Of course, the coaxial line loss and swr at this point determine the actual forward power delivered to the antenna by the transmission line. A high swr results in excessive reflected power, which must be subtracted from the forward power and added to the line loss.

b. **Ssb Transmitters.** The technique of measuring transmitter output power in the ssb transmitter is identical to that used for am transmitters. Power is expressed, however, in the case of the ssb transmitter, in watts of two-tone peak envelope power (PEP) instead of single-tone average power in watts, which is usual for the am transmitter. In addition to power output measurement, the metering of plate current, screen current, plate voltage, grid current and grid bias voltage protects transmitters operating at high power. The directional wattmeter is a much more accurate determination of the power output of the equipment, but is limited to unbalanced output. Certain transmitters used in FAA are operated into a balanced transmission line, for example, a 600-ohm open-wire line to a rhombic antenna. In order to measure the output power in such a system, it is necessary to use series rf ammeters in each side of the open-wire line. In this manner antenna current and the impedance of the line will give an accurate indication of the power actually delivered to the line. Directional wattmeters used with ssb transmitters and the associated forward power and reflected power meters may be installed as part of the transmitter or station design. Figure 1 shoes various ways a transmitter is metered for power output and swr. The 1330 hf transmitters are equipped with a forward power meter and a vswr meter. The vswr meter readings are valid only for single tone ssb output at the rated 5000W level.

c. **Peak Envelope Power.**

(1) The term "peak envelope power" (PEP) has been adopted to replace the term "carrier power" because the latter does not express the true power output of a transmitter. In particular in ssb, carrier power ceases to have meaning because in one or more modes of sb operation the carrier may be suppressed. The term PEP means the average power supplied to the antenna transmission line by a transmitter during one radio frequency cycle at the highest crest of the modulation envelope, taken during normal operation. There has been a tendency due to the word "peak" to consider PEP mistaken-

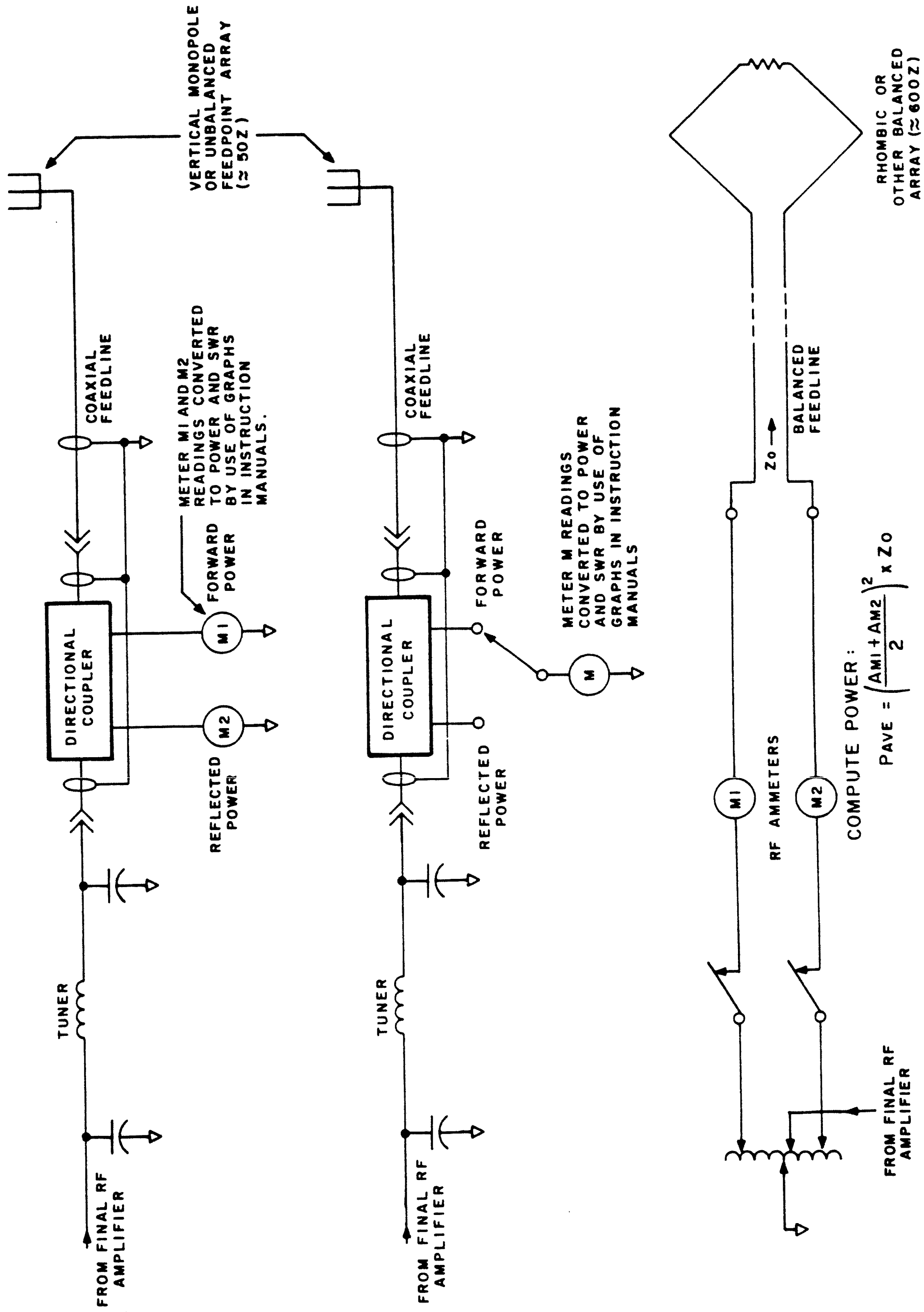
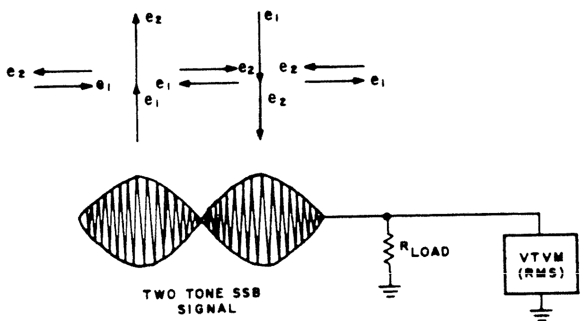


Figure 1. Three Methods for Metering Output Power in an Ssb Transmitter

ly as an instantaneous peak power value at the peak of the radio frequency cycle. This approach will yield a value twice the correct value. The true average of PEP value is the result of considering the root mean square (rms) amplitude of the radio frequency voltage (0.707 of the peak voltage) rather than the peak value. For an am transmitter with 100 percent modulation, the PEP is four times the carrier power. The PEP for a cw transmitter used for frequency-shift keying (fsk) rtty is the same as the carrier power. The most useful power test of an ssb transmitter is the two-tone test. In this case audio test tones of equal amplitude represent complex-signal ssb modulation. Figure 2 is a summary of power relationships from two-tone ssb test signals showing the correlation of average power and the power in two equal tones. The analysis can be extended to more than two audio tones applied to the transmitter; for example, a three-equal-tone test signal in which the power in each tone is one-ninth of the PEP and the average power dissipated in the load is one-third the PEP.



$V_{rms} = e_1 + e_2$ (inphase)

$P_{ep} = V_{rms}^2/R_{load} = 4e_1^2/R$ or $4e_2^2/R$
where $e_1 = e_2$

$P_{average} = e_1^2/R + e_2^2/R = 2e_1^2/R$ or $2e_2^2/R$

Therefore: (1) $P_{ep} = V_{rms}^2/R$

(2) $P_{average} = \frac{1}{2} P_{ep}$

(3) $P_{tone\,1}$ or $P_{tone\,2} = \frac{1}{4} P_{ep}$

Figure 2. Correlation of Peak Envelope and Average Power in the Ssb Transmitter

(2) Power relationships discussed in paragraph (1) do not consider the effects of distortion; however, distortion is usually so small that it can be neglected. The two-tone test of an ssb transmitter is perfect for transmitter performance tests because it provides a stable display on an oscilloscope. It also, with a spectrum analyzer, displays odd-order intermodulation distortion (imd) products. These products must be held at a low level with respect to transmitter PEP for the purity of the output of the transmitter. Some ssb transmitting equipment contains a test unit to generate a two-tone audio signal as well as a spectrum analyzer for analysis. A general procedure for imd checks using the two-tone test is in chapter 5 of the handbook proper. Figures 3 and 4 illustrate a typical two-tone test display of a spectrum analyzer, showing the two primary modulating audio tones and their amplitudes on the y-axis. Their relation to intermodulation products and the carrier at lower amplitudes is shown to the right and left of the tones along the x-axis of the display. In normal ssb communication, the carrier is not required as a carrier of intelligence. It is used only for a reference frequency to make sure that the receiving equipment is able to track precisely the transmitted signal. Carrier power to PEP relationships may be expressed as:

(a) Full carrier, which is carrier emitted at a power level 6dB or less below PEP.

(b) Reduced carrier, which is carrier emitted at a power level between 6dB and 32dB below the PEP and preferably between 16dB and 26dB below PEP. This particular usage is to achieve automatic frequency and/or gain control at the receiver.

(c) Suppressed carrier, which is carrier restricted to a power level of more than 32dB below the PEP and preferably 40dB or more below PEP. The double-sideband amplitude-modulated emission consists of a full carrier that has a power level exactly 6dB below PEP at 100 percent modulation.

3. TRANSMITTER MODULATION.

a. AM Transmitters.

(1) High-level plate modulation is measured in am transmitters with an oscilloscope and modulation monitor. The trapezoid display provides more information on system problems than the envelope display. In initially setting modulation sensitivity, the envelope pattern is adequate for determining when maximum allowable peak modulation on tone is obtained. For amplitude modulation, 95 percent is maximum, rather than 100 percent, to provide a buffer against the possibility of strong speech overmodulating the transmitter and splattering adjacent channels. When using a test tone for lineup and setting the modulation sensitivity of an am system, a 1000Hz test tone is applied, at its equivalent system level, to the transmitter modulator. The audio gain of the modulator is then adjusted to indicate exactly 95 percent on the oscilloscope. A further refinement of modulation is using an average talker on the microphone at the operating position to provide a standard test count. During this process, transmitter modulation is observed on the oscilloscope, and the modulator audio gain is adjusted for 95 percent maximum on voice peaks. The typical am transmitter signal modulated 100 percent occupies about 6kHz of channel space. Speech com-

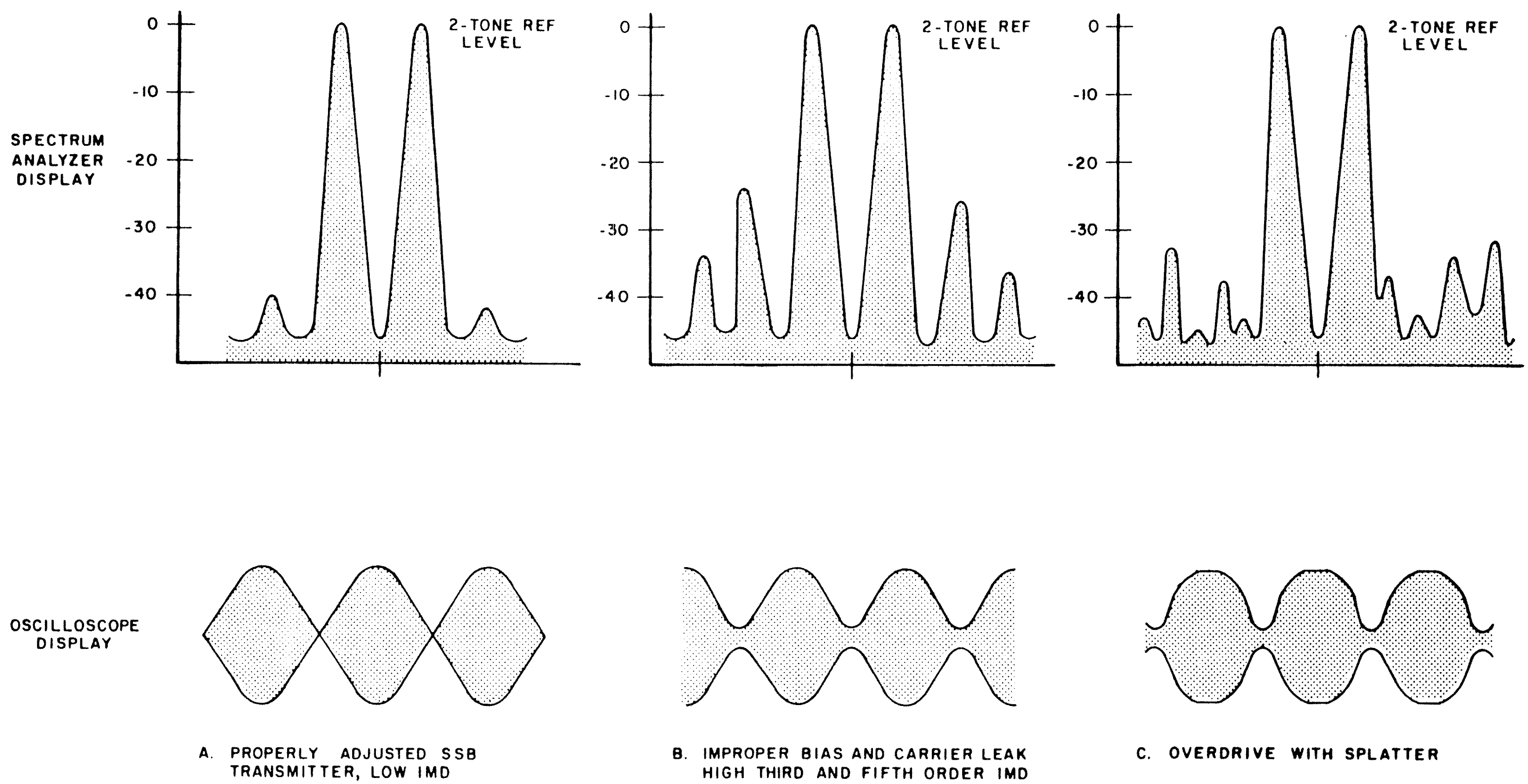


Figure 3. Spectrum Analyzer and Oscilloscope Patterns of Two-Tone Ssb Tests

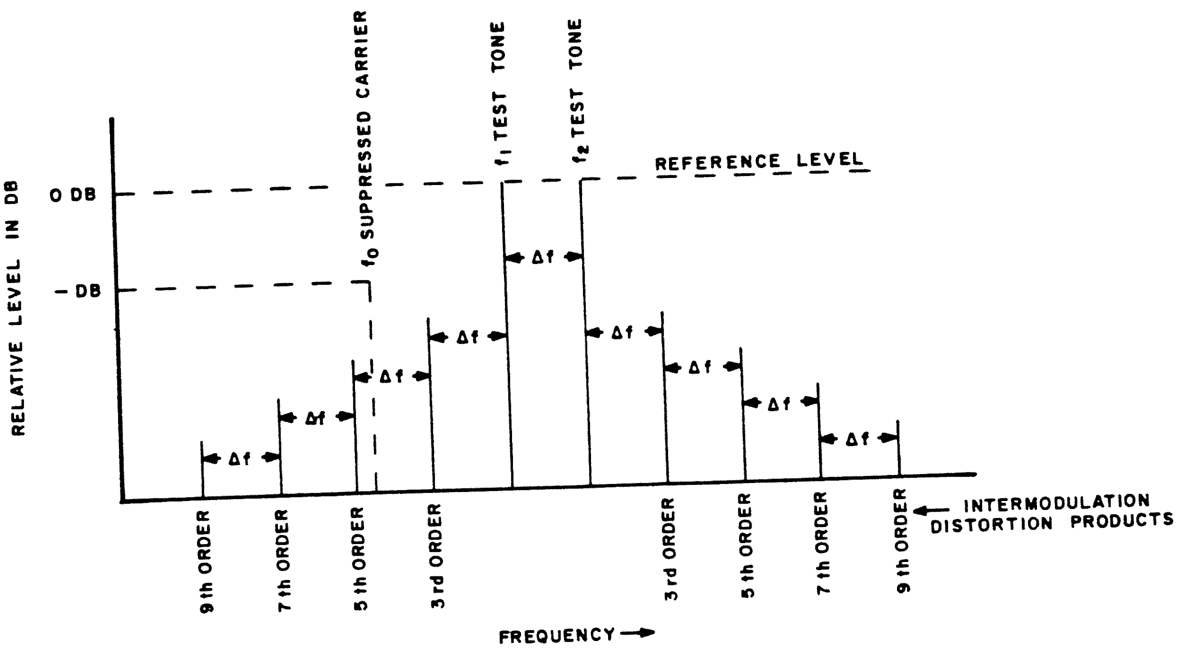


Figure 4. Relationship of Two-Tone Amplitudes to Carrier and Intermodulation Distortion in an Ssb Signal

ponents over a band of approximately 100Hz to 3000Hz are combined with the am radio frequency carrier to yield two sidebands occupying a frequency spectrum from about 3000Hz below the carrier to 3000Hz above. Compared to ssb, this is a relatively wasteful system, for the spectrum occupancy with ssb transmission carrying equivalent intelligence is only about 3000Hz.

(2) Modulation percentage measured on a symmetrical input signal is based on the fact that the modulation signal has equal peak positive and negative amplitudes. This is true of an audio sine wave, such as 1000Hz test tone modulating a transmitter. The formula for such modulation is:

$$\text{Percent modulation} = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \times 100$$

If the modulating signal is unsymmetrical, depth of modulation can be both "upward" and "downward," and percentage of modulation is by two formulas:

$$\text{Percent upward modulation} = \frac{E_{max} - E_{min}}{E_{min}} \times 100$$

$$\text{Percent downward modulation} = \frac{E_{min} - \text{min envelope downpeak}}{E_{min}} \times 100$$

In unsymmetrical audio modulation, it is possible to have more than 100 percent upward modulation while having 100 percent downward modulation, and no distortion, as long as the modulated waveform exactly reproduces the modulating waveform.

b. **Transmitters.** There is no need for an elaborate method of measuring modulation in the ssb system (or linear power amplifier) because 100 percent modulation is achieved and can be observed on an oscilloscope when the audio input to the ssb exciter is of the proper level to provide undistorted rated transmitter output. The ssb transmitter usually employs audio compression in the exciter to prevent overdriving the rf amplifiers. This compression is similar to automatic gain control (agc) in a receiver in that a large signal causes the gain to be reduced through the system and the rate of gain reduction is that corresponding to the syllabic rate of speech. The ssb system employs automatic level control (ALC), or automatic load control, to ensure that the output linear amplifier is not driven beyond linearity. Various kinds of distortion on an ssb signal are illustrated in figure 3. Among the most common faults that may occur on an ssb signal are overdrive, which results in peak clipping, and insufficient loading of the linear amplifier. Additional problems are incorrect amplifier bias and unwanted modulations caused by carrier leak-through. To reiterate the principal advantage of a two-tone test for observing modulation of an ssb signal is that it produces a stable oscilloscope display easy to examine for defects. On the other hand, it is impossible to evaluate an active speech waveform. Many ssb transmitters have a sniffer circuit in the final rf stage to direct a small amount of rf energy to a front panel jack on the transmitter so that modulation or drive can be observed while the transmitter is in operation. Procedures for the use of the oscilloscope and spectrum analyzer in ssb performance checks are contained in chapter 5 of the handbook proper or in referenced instruction books.

4. SPURIOUS EMISSION.

Spurious emission is undesired transmitter radiation of two basic types: spurious responses outside the passband, and imd and other distortion in or near the passband. Harmonics and parasitic oscillations are the principal kind that fall outside the passband; these may include emission of frequency synthesizers and broadband noise arising in lower level stages amplified by the final power amplifiers. The best instrument on which to observe any of these unwanted disturbances is the spectrum analyzer. A receiver tunable to the frequency of interest is also useful if coupled to a suitable output indicator. The most effective test of the output purity of an ssb transmitter output is the simultaneous application of two equal-amplitude audio tones (the two-tone test). The two-tone test has become a standard test because: (a) one signal is insufficient to produce intermodulation for observation; (b) more than two signals result in so many intermodulation products that analysis is impractical; (c) two or more sine-wave tones of equal amplitude place more demanding requirements on the ssb system than it is likely to encounter in normal use. In effect, a two-tone test signal represents a very complex system that provides a very clear means for observing a number of deficiencies in the system. The two-tone test that generates a number of intermodulation products is shown in figure 4. In this illustration, the relationship of the carrier and the two test tones is shown on the x-axis of the coordinate system. The even- and odd-order products that may result from both rf and af intermodulation are plotted on the y-axis, as related to the two desired modulating audio frequencies; the carrier, and any other signals in the passband. Figure 4 is a simplified illustration of the relationship of test tones, odd-order products, and the carrier and shows the logarithmic relationship that is expected in a normally operating system. The products of the most significance are those of odd order, especially the third- and fifth-order products. The even-order products always fall so far outside the frequencies of interest that they are not observed nor do they affect the passband. (They can interfere with other service, however). The seventh- and ninth-order products usually are so greatly attenuated with respect to PEP that they can be neglected. The fifth-order product is generally much lower than the third order and also may be neglected in actual testing. However, the third-order intermodulation products must always be evaluated. Chapter 5 of the handbook proper contains a generalized procedure (using a spectrum analyzer) for checking imd and other spurious responses. In figure 4, it should be noted that the spacing between each tone of the pair and the adjacent intermodulation products, and the spacing between subsequent intermodulation products is equal to the spacing f_1 between the two basic tones. The imd signals adjacent to the desired tones are the third-order products. The next pair are the fifth-order, spaced equally outside the third order products; the next pair are the seventh, then the ninth, and so on. The order of a distortion product is the sum of the coefficients in the frequency expression. For example, the third-order products will be twice the frequency of one desired tone minus the frequency of the opposite tone. The fifth-order product is three times the frequency of one tone minus two times the frequency of the other. The odd-order products falling in or near the desired transmission band are the most objectionable because, once generated, they cannot be eliminated by either the transmitter or the receiver. The signal-to-distortion ratio is the ratio of either of the two desired test tones to the largest undesired products expressed in decibels. A signal-to-distortion ratio of at least 35dB to 40dB is considered acceptable for an hf ssb communication system. Unless unusual cancellation exists in the power amplifier, the third-order imd product will be the largest, and all higher order products will be progressively smaller.

5. RF SIGNAL GENERATORS AND THE COMMUNICATION SERVICE MONITOR (CSM).

a. An essential test equipment for receiver tests is a generator of rf microvolts ranging typically from 0.1µV to 100,000µV. The rf output is typically 50 ohms, controlled with an adjustable output attenuator calibrated to read directly in terminated microvolts. Therefore, when the generator is connected to 50-ohm receiver antenna input terminals, the generator actually delivers to the receiver the level indicated on its attenuator dial. Formerly, some generators were of unterminated (open circuit) output and required a 6dB pad between the generator output to match the external circuit being tested, so that the output attenuator was properly calibrated. Use of the pad at the output of the older generators required twice the voltage from the unterminated generator to produce a terminated level at the device being tested. From this resulted the concept of standard test voltage (STV) in FAA equipment specifications, standards and tolerances, and maintenance procedures. Presently, it is unnecessary to specify or use STV levels, or a pad, where the circuit under test matches the 50-ohm generator output.

b. Acquisition of the communication service monitor (CSM), equipped with the stable and accurate frequency synthesizer, has eliminated the electronic frequency counter as a monitor of the test frequency during receiver tests. The direct-reading CSM can be set exactly to the required frequency; and such tests as if bandwidth and if bandwidth nonsymmetry can be made with confidence that frequency drift and setup error has not occurred.

c. An early model CSM was procured in a limited quantity for FAA evaluation, and was allocated to only a few facilities. This was the Singer-Metrics FM-10CS. The national procurement was for a simpler version, the CSM-1. The procedures in this handbook are based on the latter unit.

6. RECEIVER SENSITIVITY.

a. Sensitivity tests of communication receivers are of two basic types. The first yields the lowest rf voltage (in microvolts) impressed at the antenna terminals that will produce a specified af power at the audio output loaded in its proper impedance. This is useful at the lower frequencies (e.g., below about 25MHz) where atmospheric noise is the dominant noise of the system. The second provides the lowest rf antenna terminal voltage (in microvolts) for a specified signal-plus-noise to noise ratio, also measured at the audio output of the receiver. The latter test is the better of the two for vhf and uhf receivers, where receiver noise dominates. Another form of sensitivity test is the front-end figure of merit of the receiver, or noise figure as it is usually called. This test, normally useful with receivers of 30MHz operating frequency and above, is based on the ratio (expressed in dB) of noise power developed in the ideal (quiet) receiver to noise power developed in the actual (noisy) receiver. It is particularly useful for frequency-modulated (fm) receivers used in communication link systems.

b. Test equipment required for the rf voltage input for specified audio frequency (af) output power, or for signal-plus-noise output, is (1) a stable rf signal generator tunable to the receiver's frequency range with an accurate rf output level attenuator, and (2) an audio power level meter to measure the af power output or receiver noise power. For noise figure tests, a noise-figure test set with calibrated noise source is required.

7. RECEIVER SELECTIVITY AND IF BANDPASS SYMMETRY.

a. The selectivity of a receiver is a measure of its ability to reject unwanted signals. Selectivity is almost exclusively determined by the intermediate-frequency (if) stages of a receiver. In modern receivers equipped with crystal-filter elements in the if stages, it is the crystal filter that determines the bandpass characteristic. The typical measure of selectivity is based on the curve formed by sweeping an rf signal, applied at the antenna terminals, symmetrically above and below the center, or channel, frequency of interest. The receiver agc detector circuit dc voltage draws this curve when metered with a dc voltmeter. (Most receivers are equipped with an agc test jack at which the changes in agc voltage may be observed.) As the channel frequency is approached by the generator from below in frequency, the curve is seen to pass symmetrically from a level well below a point 60dB below agc threshold, through a point 6dB below the agc threshold. Then when the curve reaches its nose, or maximum excursion, a flat-top region (with some ripple) will be observed before it falls away in mirror image on the higher frequency side. Figure 5 illustrates a typical if selectivity curve of a receiver having a crystal filter. The 6dB and 60dB points that are the standard reference levels for selectivity are shown. The 6dB levels are chosen as checkpoints as it is necessary to have a given minimum bandwidth for undistorted, received-signal, double-sideband reception. The 60dB levels are chosen similarly to ensure that the lower skirt slope characteristics do not exceed the maximum actually needed for the passband. The standard reference levels for WR-100 receivers are the 6dB and 80dB points.

b. Symmetry of the if passband is essential to prevent skirt distortion of one sideband or the other during reception. Symmetry is dependent on the accuracy of the first oscillator crystal and on troublefree if and crystal filter stages. Usually, an off frequency crystal or mistuning of if stages (or a defective filter) will cause large out-of-tolerance symmetry measurements, which are measured in percent of nonsymmetry. Figure 5 is an if passband with some nonsymmetry evidenced.

8. FREQUENCY STABILITY.

a. To provide reliable communication, a receiver must stay precisely tuned to the incoming rf signal. For this reason (in ssb precise timing is more important than in am), the modern receiver uses oven-controlled, local oscillator crystals having tight stability specifications. As mentioned in paragraph 7, an inaccurate or drifting crystal-controlled local oscillator circuit will cause the if frequency generated in the mixer circuit to shift and thereby skew the useable passband to affect if symmetry, possibly to the point of great signal degradation and loss of contact.

b. The frequency-synthesized communication service monitor (CSM-1) is a precision substitute for the older, tunable rf signal generators and Gertsch frequency meters, which necessitated use of an external electronic frequency counter to make most measurements. The Gertsch frequency meters types FM-3 and FM-6 should be avoided when applying the procedures of this order.

9. MISCELLANEOUS TESTS.

Sometimes it is useful to evaluate a receiver for other than the basic parameters discussed in paragraphs 5 through 8. Such factors as intermodulation, spurious oscillation in amplifiers, excessive noise developed in the receiver, audio frequency response, and agc response can be measured. However, they are not included in this handbook because they are primarily used in design qualification tests or for troubleshooting.

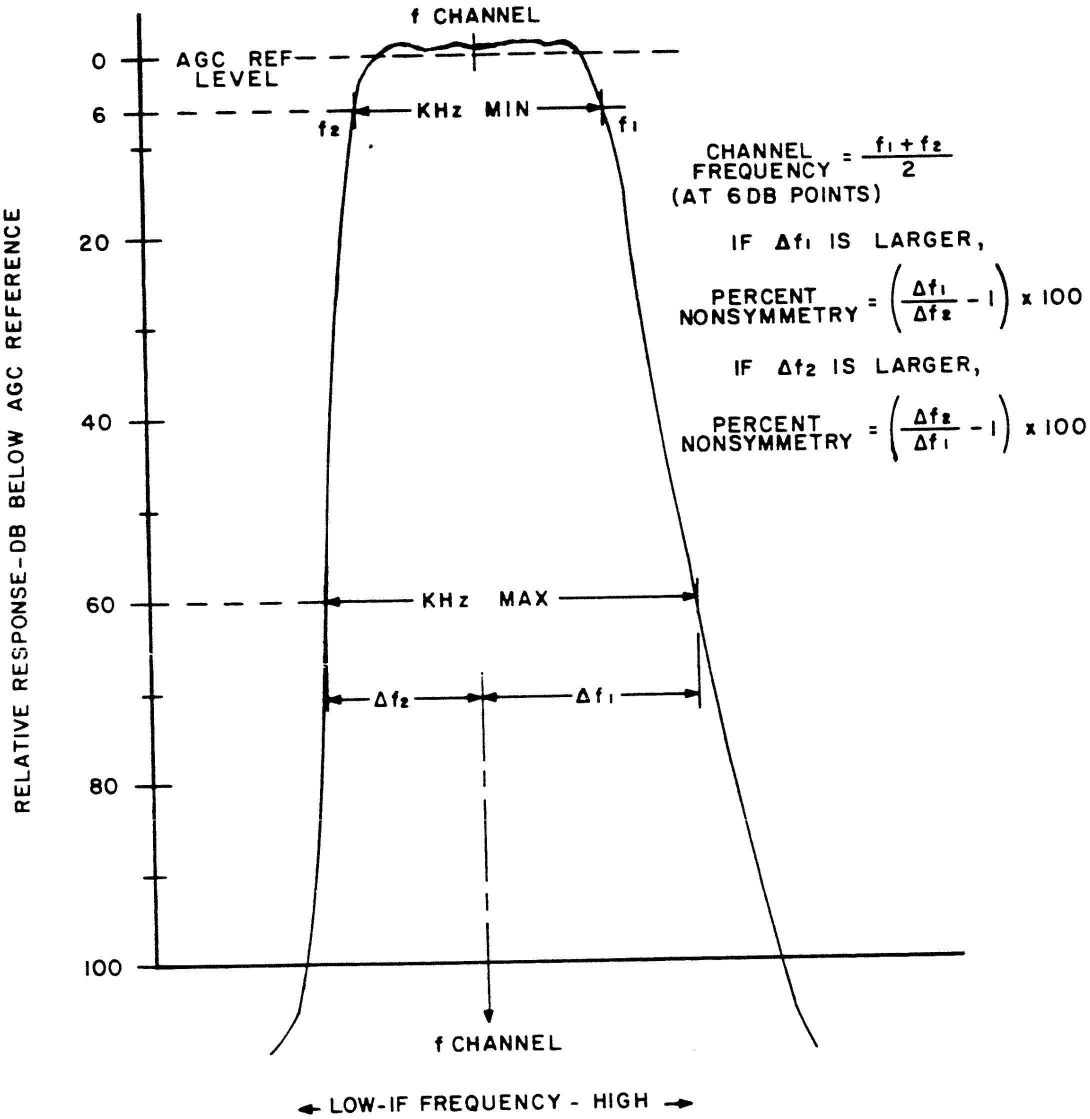


Figure 5. Typical Receiver IF Selectivity Response

APPENDIX 3. TRANSMITTER AMPLITUDE MODULATION (AM) MEASUREMENTS

1. GENERAL.

To measure amplitude modulation on test tone or voice peaks, connect the transmitter to a dummy load, a modulation monitor, and an oscilloscope, as shown in figures 1 and 2.

2. THE TRAPEZOIDAL PATTERN.

a. The trapezoidal modulation pattern offers an excellent method of checking transmitter distortion and modulation percentage. Figure 3 illustrates how the rf and audio signals combine to produce the trapezoidal pattern.

WARNING: High voltage is present on external test leads when making this modulation check. Observe proper precautions.

(1) Do not apply the modulated rf carrier directly to the vertical deflection plates. Obtain suitable output from the modulation monitor, which converts the modulated transmitter rf output signal to a 100kHz modulated rf signal. Then apply this signal to the vertical input of the oscilloscope.

(2) Only a small portion of the audio voltage is applied to the horizontal deflection plates of the oscilloscope. Observe caution to avoid contacting the high voltage present at the modulator test points.

NOTE: Avoid using the audio output from the modulation monitor for horizontal drive to the oscilloscope. Use audio ahead of the modulated stage of the transmitter, preferably the final output of the modulator, for the horizontal drive source.

(3) Figure 1 shows a typical test setup for use with a uhf single-channel transmitter. A similar setup for vhf transmitters will work equally well by bridging the oscilloscope horizontal input across the audio signal input of the transmitter modulator.

b. Many modulation problems can be identified by analysis of the trapezoidal pattern. Figure 4, part A, shows a normal 100-percent modulated signal with good linearity. Convex or concave sloping sides indicate linearity problems in the final amplifier. Part B of figure 4 shows an overmodulated condition. Part C indicates an audio phase shift in the transmitter, common to some degree in most transmitters. Use a simple phase-shift network in the oscilloscope horizontal input line. This phase-shift network may be made up of a 0.01μF capacitor in series with the audio line and a 50,000-ohm potentiometer in parallel with the audio line. Parts D through F show various kinds of distortion. Part G is an overmodulated transmitter with excessive screen voltage on the class C modulated stage.

3. THE ENVELOPE PATTERN.

a. Figure 5 shows various modulation patterns with the oscilloscope adjusted and connected for the envelope pattern technique (test arrangement in figure 2). Part A of figure 5 is a normal, 100-percent modulated pattern. Part B shows a normal overmodulated pattern. Part C is an overmodulated pattern showing the effects of regenerative feedback. Part D is an overmodulated pattern showing the effects of excessive screen voltage in relation to the plate voltage in the modulated stage. Part E illustrates crossover distortion caused by excessive grid bias on the modulator tubes. Part F is a pattern caused by speech amplifier clipping.

b. Figures 6 and 7 are nomographs for determining percent of modulation (by either trapezoidal or envelope pattern) without calculations.

4. MODULATION ADJUSTMENT TECHNIQUES.

Set the transmitter voice modulation as close as possible to 95 percent without overmodulating the transmitter. The technique is simple. Request a controller to transmit a standard voice test count, and increase the transmitter audio gain until a few points of overmodulation can be seen on an oscilloscope. Then slightly decrease the transmitter audio gain so that the overmodulation peaks no longer occur.

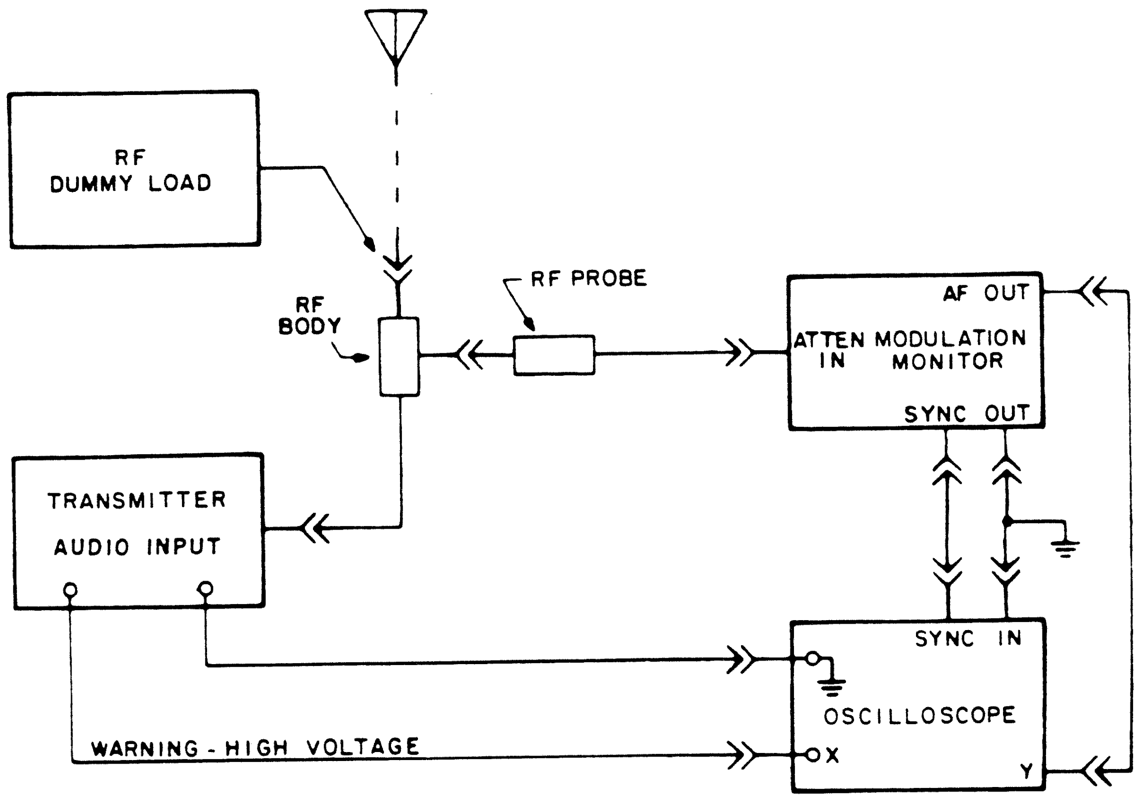
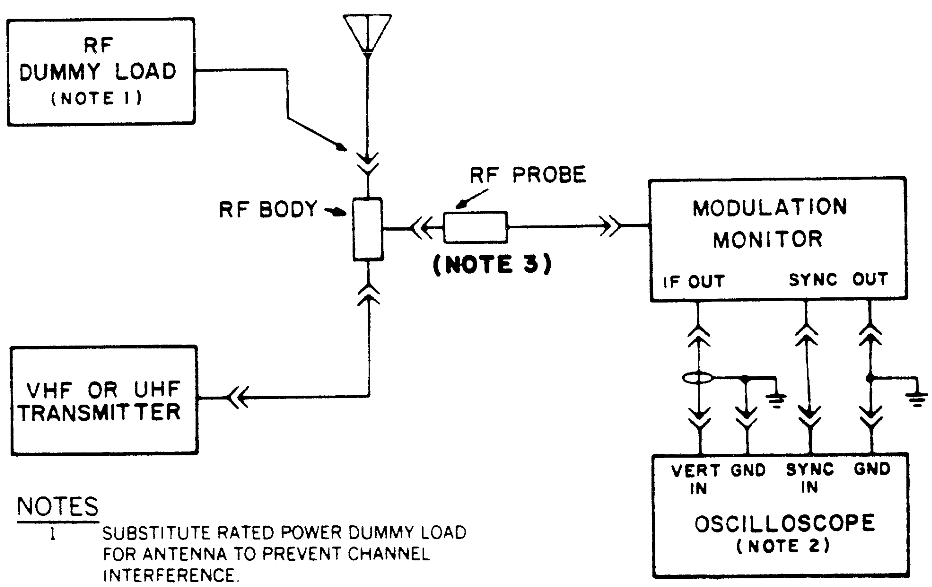


Figure 1. Modulation Measurement by the Trapezoidal Pattern



NOTES

1 SUBSTITUTE RATED POWER DUMMY LOAD FOR ANTENNA TO PREVENT CHANNEL INTERFERENCE.

2 TEST ARRANGEMENT IS FOR SINUSOIDAL DISPLAY

3 AT SOLID-STATE, COLLOCATED TRANSMITTER/RECEIVER SITES, THE INTERMEDIATE FREQUENCY (IF) OF THE MODULATED SIGNAL MAY BE OBTAINED FROM THE RECEIVER IF OUTPUT JACK, J10, IF A MODULATION MONITOR IS NOT AVAILABLE.

Figure 2. Modulation Measurement by the Envelope Pattern

APPENDIX 7. ORIENTATION OF HIGH-FREQUENCY (HF) DIRECTIVE ANTENNAS

1. GENERAL.

a. Because a high-frequency (hf) antenna for point-to-point (ptp) operation is highly directive, it naturally must be pointed exactly in the proper direction. Radio waves in the hf bands follow a great-circle route as they are reflected by the ionosphere. Therefore, it is necessary to calculate the transmitting azimuth of the great-circle route to the receiving station. The same is true for the reverse path: the distant station must point its transmitting antenna at the correct great-circle azimuth to the distant (local) receiving station. Figure 2-40, in chapter 2, illustrates the three great-circle models from which calculation are made: part A, when both receiving and transmitting stations are north of the equator; part C, when both receiving and transmitting stations are south of the equator; and part B, when the great-circle path spans the equator. Azimuth and distance calculations described in this appendix will assist the reorienting of existing antennas if there is a need to relocate circuits or relocate transmitter or receiver stations. They are useful to initially orient or reorient rotatable log-periodic, quad, or yagi hf directional antennas such as may be used in the interregional emergency network or ship-to-shore circuits. Great-circle charts centered on large cities throughout the world are published and may be used for rough determinations of great-circle azimuth.

b. The calculations involve the use of natural trigonometric functions. These functions may be obtained from published tables or, most conveniently, directly from any one of several "slide-rule" electronic calculators. The latter instrument considerably eases the labor and improves the accuracy of great-circle calculations.

c. The stations marked A and B in figure 2-40 correspond to the notation A and B in the formulas given in the procedure below.

2. PRELIMINARY PROCEDURE.

To assist in obtaining a concept of the great-circle arc to stretch between the transmitting and receiving points on the earth, a moderate-sized library globe may be used initially to lay out the path. From this, a rough determination of latitude, longitude, and azimuth can be obtained. More precise latitude and longitude in degrees and minutes are required for actual great-circle calculations. For these, a large-scale map or charts of Mercator projection showing the individual transmitting and receiving sites are suitable. If necessary, the data can be obtained through survey procedures. In preparing for the calculations, it is useful to ascertain the mathematical signs (+ or −) to be used with the various functions in paragraph 3.

Both Points in East Longitude	*Both Points in West Longitude*	*One Point in East Longitude; One Point in West Longitude*
If longitude of A is greater than longitude of B, A is east of B; if less, A is west of B.	If longitude of A is greater than longitude of B, A is west of B; if less, A is east of B.	If A is in east longitude, A is east of B unless arithmetic sum of the longitudes is greater than 180°. Then A is west of B. If A is west longitude, A is west of B unless arithmetic sum of the longitudes is greater than 180°.

3. **BASIC FORMULAS AND SYMBOLS FOR CALCULATIONS.**

a. There are three basic formulas for determining great-circle data. They are:

(1)

$$\text{Cos } D_{a-b} = \text{Sin } L_a \text{ Sin } L_b + \text{Cos } L_a \text{ Cos } L_b \times \text{Cos } L_o$$

(2) $$\text{Sin } C_a = \frac{\text{Cos } L_b \text{ Sin } L_o}{\text{Sin } D_{a-b}}$$

(3) $$\text{Sin } C_b = \frac{\text{Cos } L_b \text{ Sin } L_o}{\text{Sin } D_{a-b}}$$

b. Formula (1) computes the great-circle distance from A to B in minutes of arc or nautical miles (1 minute of arc = 1 nautical mile = 1.853km = 1.152 statute miles).

c. Formula (2) computes the azimuthal direction of B from A, in degrees east or west from north in the northern hemisphere and from south in the southern hemisphere.

d. Formula (3) computes the azimuthal direction of A from B.

e. Explanation of symbols.

(1) L_a = latitude of station A, positive for north latitude, negative for south latitude.

(2) L_b = latitude of station B, positive for north latitude, negative for south latitude.

(3) L_o = difference in longitude between A and B.

(4) C_a = direction of B from A (great circle).

(5) C_b = direction of A from B (great circle).

4. **SURVEYING THE ANTENNA.**
The following steps apply to a rhombic antenna. The end poles are aligned along the azimuthal axis of the array. The azimuthal angles are C_a and C_b calculated in paragraph 3. The angle used depends on whether the local station is at point A or at point B. Refer to the plan view illustration of the rhombic antenna, figure 1, for construction elements of the antenna.

a. Place a transit at the design center of the antenna, with plumb line over the center stake. Adjust the transit for 0° elevation angle on the vertical circle.

b. Adjust the horizontal circle and vernier for 0° at true north.

c. Swing the transit horizontally from 0° to the C_a or C_b azimuth on the horizontal circle.

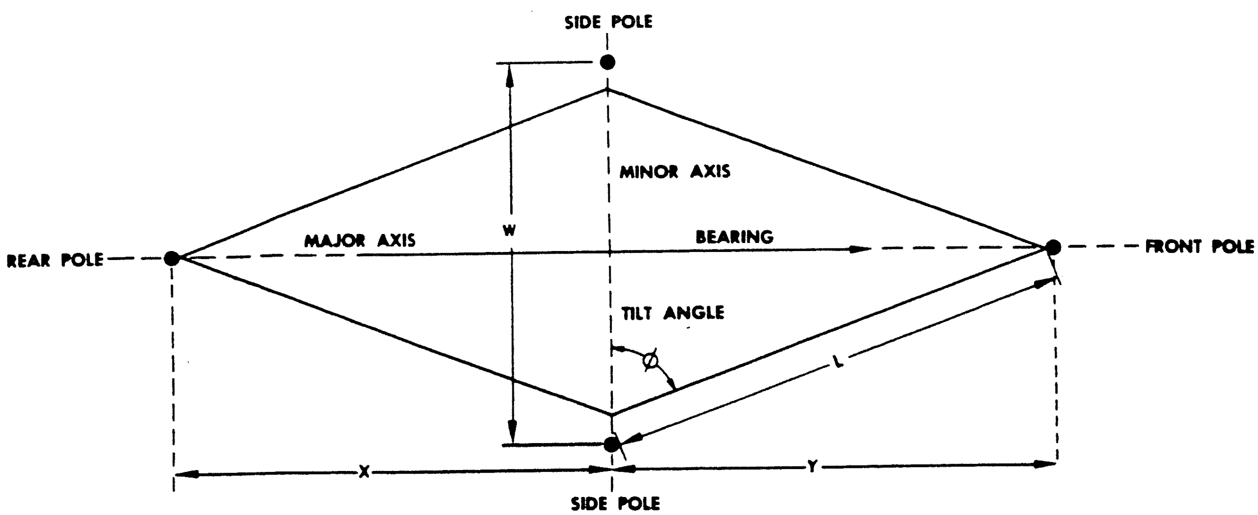


Figure 1. Plan View of Rhombic Antenna

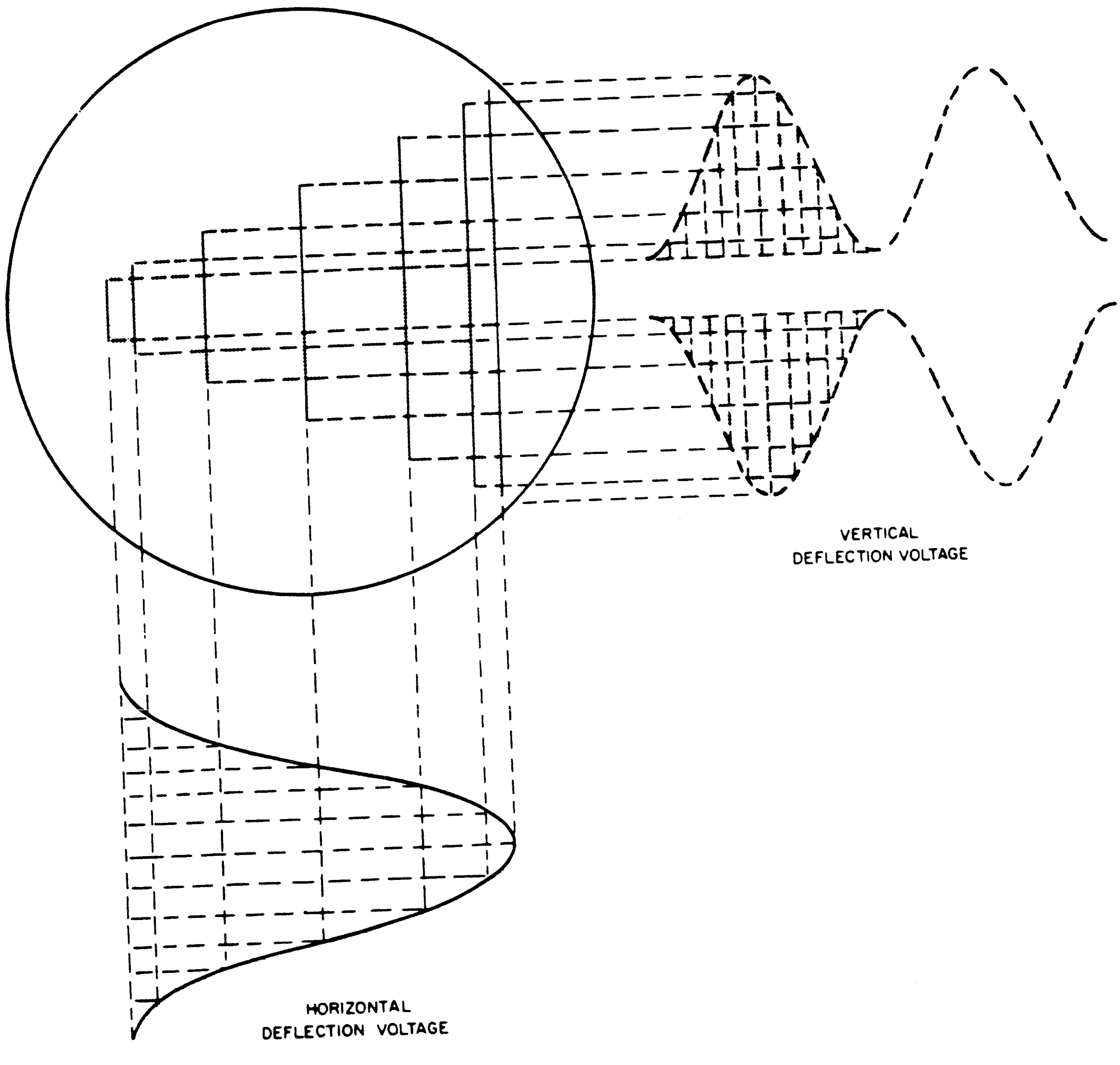


Figure 3. Production of Trapezoidal Pattern

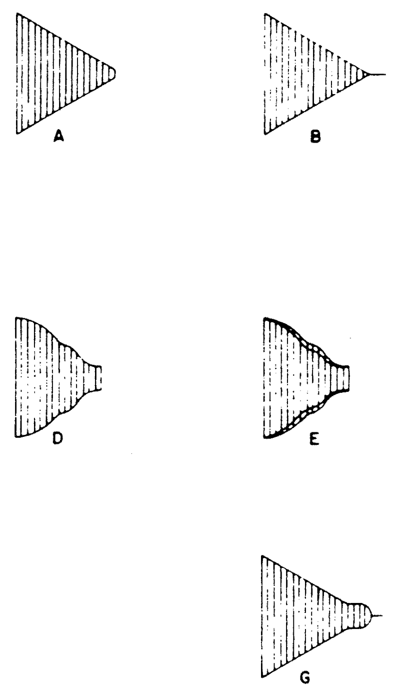


Figure 4. Various Trapezoidal Patterns

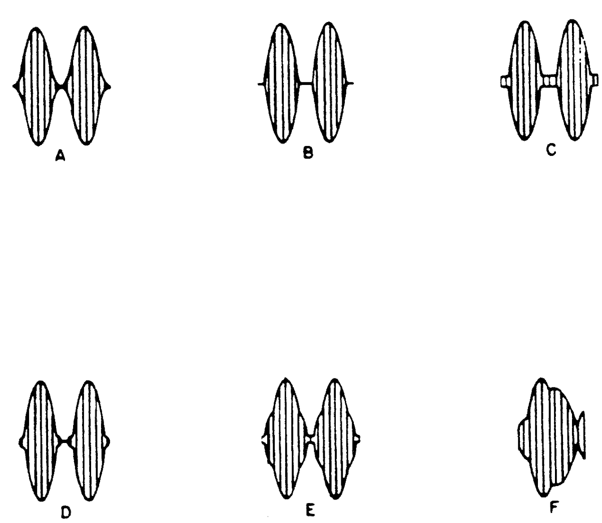


Figure 5. Various Envelope Patterns

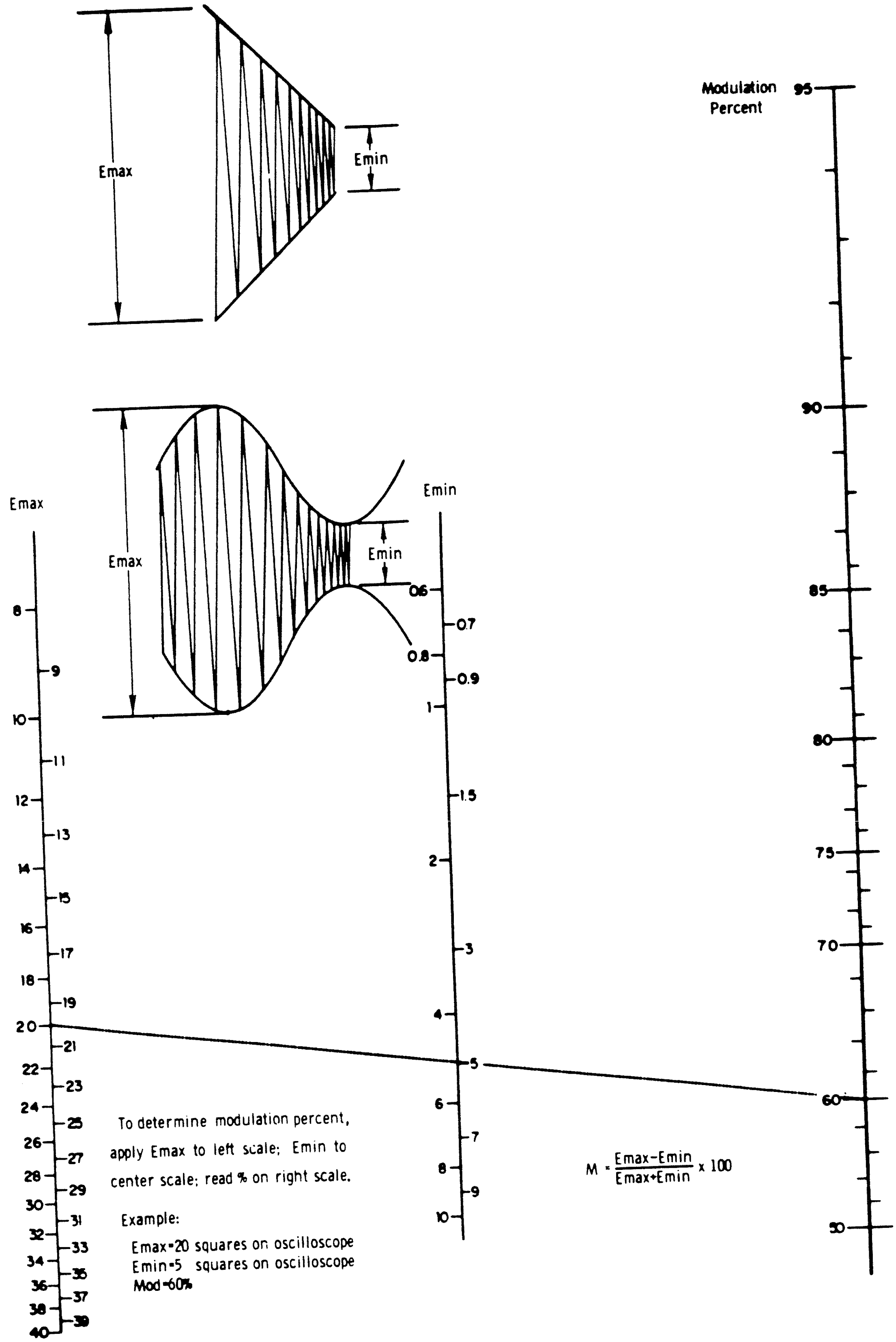


Figure 6. Nomograph for Percentage of Modulation, 50 to 95 Percent

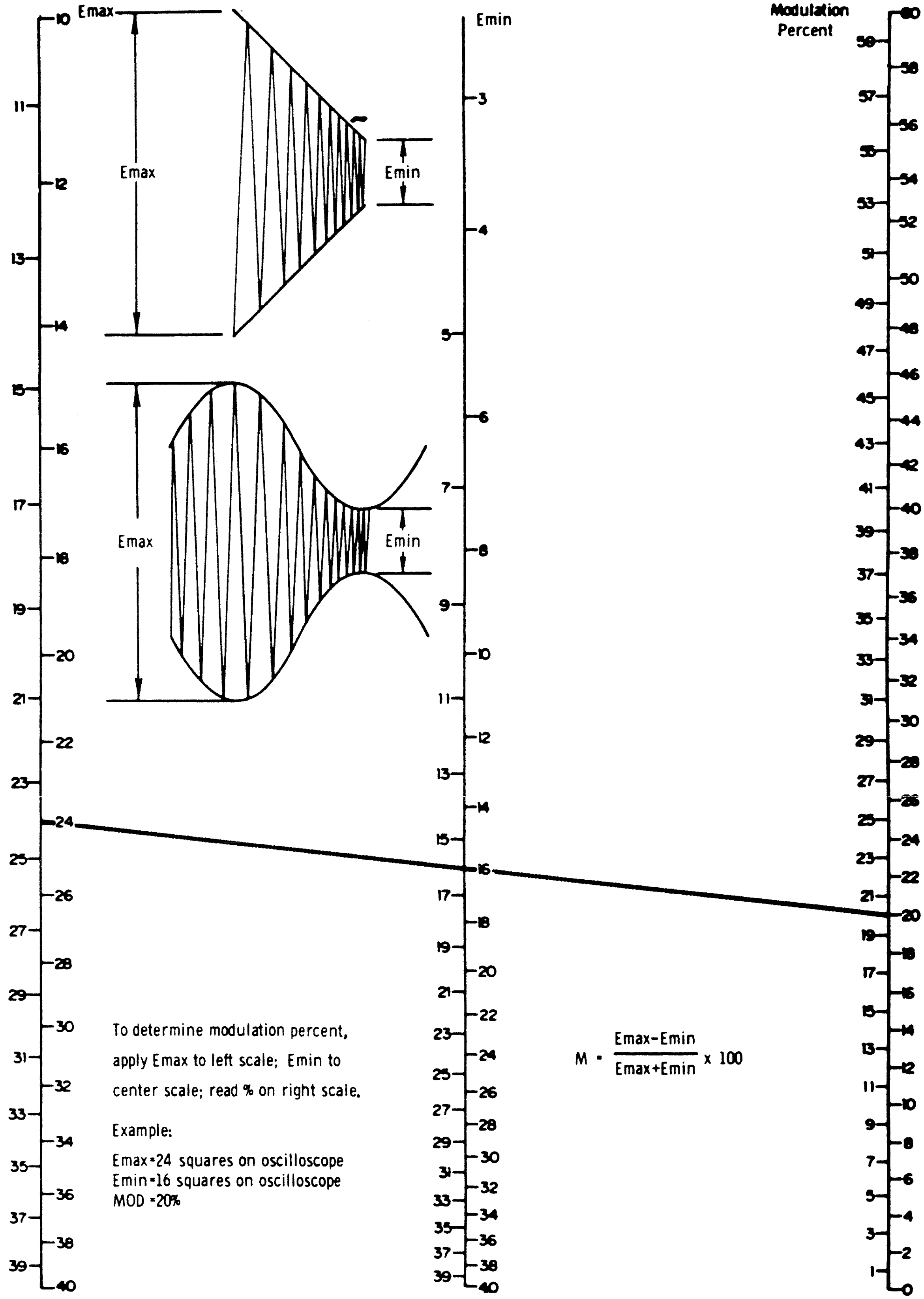


Figure 7. Nomograph for Percentage of Modulation, 0 to 60 Percent

APPENDIX 4.
REFERENCE DATA FOR AUDIO FREQUENCY MEASUREMENTS

1. GENERAL.

This appendix provides graphs, charts, and a table for assisting in the calculations that are a necessary part of measuring and evaluating audio frequency (af) and noise parameters in the point-to-point (PTP) or air-ground (a-g) communication channel.

2. DB-VU-DBM UNIT CONVERSION.

Figure 1 is a chart that is useful in converting from one audio unit of value to another. It provides both 1-milliwatt and 6-milliwatt reference scales and a scale of volts root-mean-square (rms) across a 600-ohm impedance.

3. RMS VOLTS TO POWER LEVEL CONVERSION.

Figure 2 is a graph of volts rms to power in dBm across various load impedances.

4. METER CORRECTION GRAPH.

Figure 3 permits correction of meter readings made with the same meter across various resistive load impedances.

5. DECIBELS ABOVE AND BELOW A 1-MILLIWATT REFERENCE LEVEL.

Table 1 is numerical data, accurate up to five significant figures, relating dB, volts rms, and dBm referred to 1 milliwatt in 600 ohms.

Table 1. DECIBELS ABOVE AND BELOW A REFERENCE LEVEL OF 1 MW INTO 600 OHMS

dB Down		*Level*	*dB Up*	
Volts	*Milliwatts*	*dBm*	*Volts*	*Milliwatts*
0.774 6	1.000	−0+	0.774 6	1.000
0.690 5	0.794 3	1	0.867 1	1.259
0.616 7	0.631 0	2	0.975 2	1.585
0.548 4	0.501 2	3	1.094	1.995
0.488 7	0.398 1	4	1.228	2.512
0.435 6	0.316 2	5	1.377	3.162
0.388 2	0.251 2	6	1.546	3.981
0.346 0	0.199 5	7	1.734	5.012
0.308 4	0.158 5	8	1.946	6.310
0.274 8	0.125 9	9	2.183	7.943
0.244 9	0.100 0	10	2.449	10.000
0.218 3	0.079 43	11	1.748	12.59
0.194 6	0.063 10	12	3.084	15.85
0.173 4	0.050 12	13	3.460	19.95
0.154 6	0.039 81	14	3.882	25.12
0.137 7	0.031 62	15	4.356	31.62
0.122 8	0.025 12	16	4.887	39.81
0.109 4	0.019 95	17	5.484	50.12
0.097 52	0.015 85	18	6.153	63.10
0.086 91	0.012 59	19	6.905	79.43
0.077 46	0.010 00	20	7.746	100.00
0.043 56	0.003 16	25	13.77	316.2
0.024 49	0.001 00	30	24.49	1.000W
0.013 77	0.000 316	35	43.56	3.162W
0.007 746	0.000 100	40	77.46	10.00W
0.004 356	3.16×10^{-5}	45	137.7	31.62W
0.002 449	1.00×10^{-5}	50	244.9	100W
0.001 377	3.16×10^{-6}	55	435.6	316.2W
0.000 774 6	1.00×10^{-6}	60	774.6	1 000W
0.000 435 6	3.16×10^{-7}	65	1 377	3 162W
0.000 244 9	1.00×10^{-7}	70	2 449	10 000W
0.000 137 7	3.16×10^{-8}	75	4 356	31 620W
0.000 077 46	1.00×10^{-8}	80	7 746	100 000W

NOTE. The power holds for any impedance, but the voltage holds only for 600 ohms

6. CONVERSION OF NOISE UNITS.

Figures 4 and 5 are nomographs permitting the conversion of noise readings from one noise meter to another of a different noise-weighting characteristic. Conversions are possible between flat (3kHz) noise, FIA-weighting, 144-weighting, and C-message weighting in dBm, dBa, dBrn, and dBnc units.

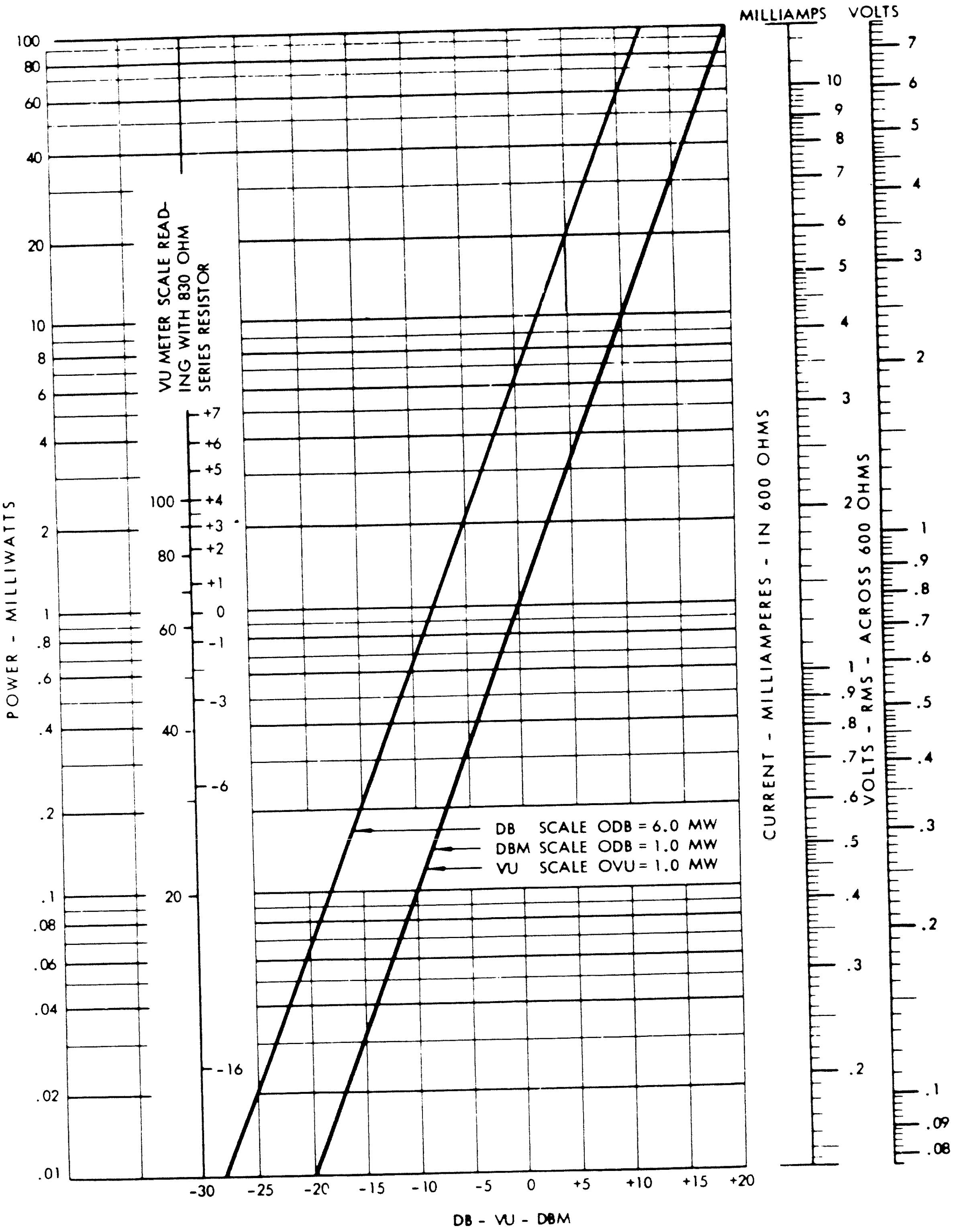


Figure 1. DB-VU-DBM Unit Conversion Chart

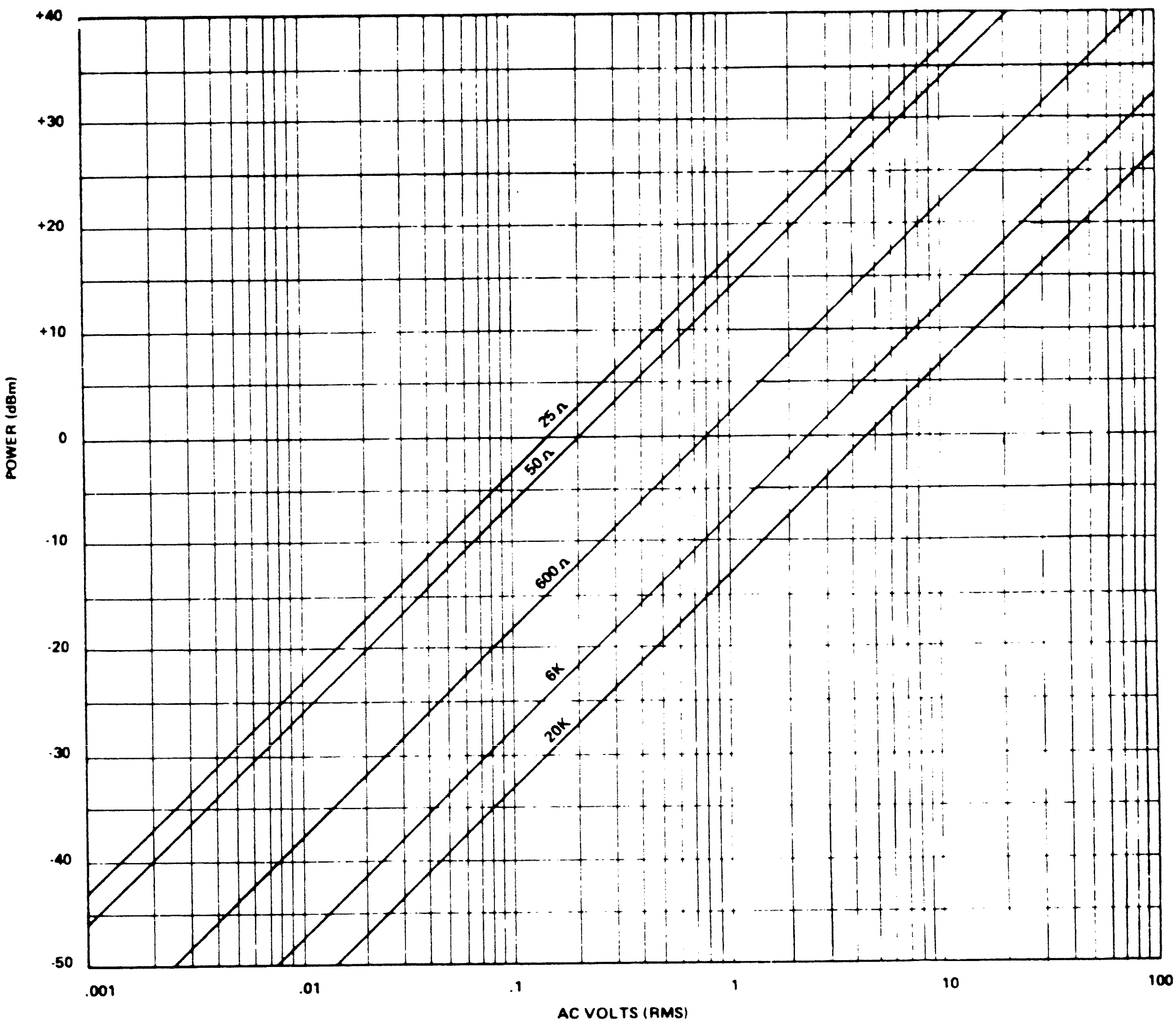


Figure 2. RMS Voltage to Power Level Conversion Chart

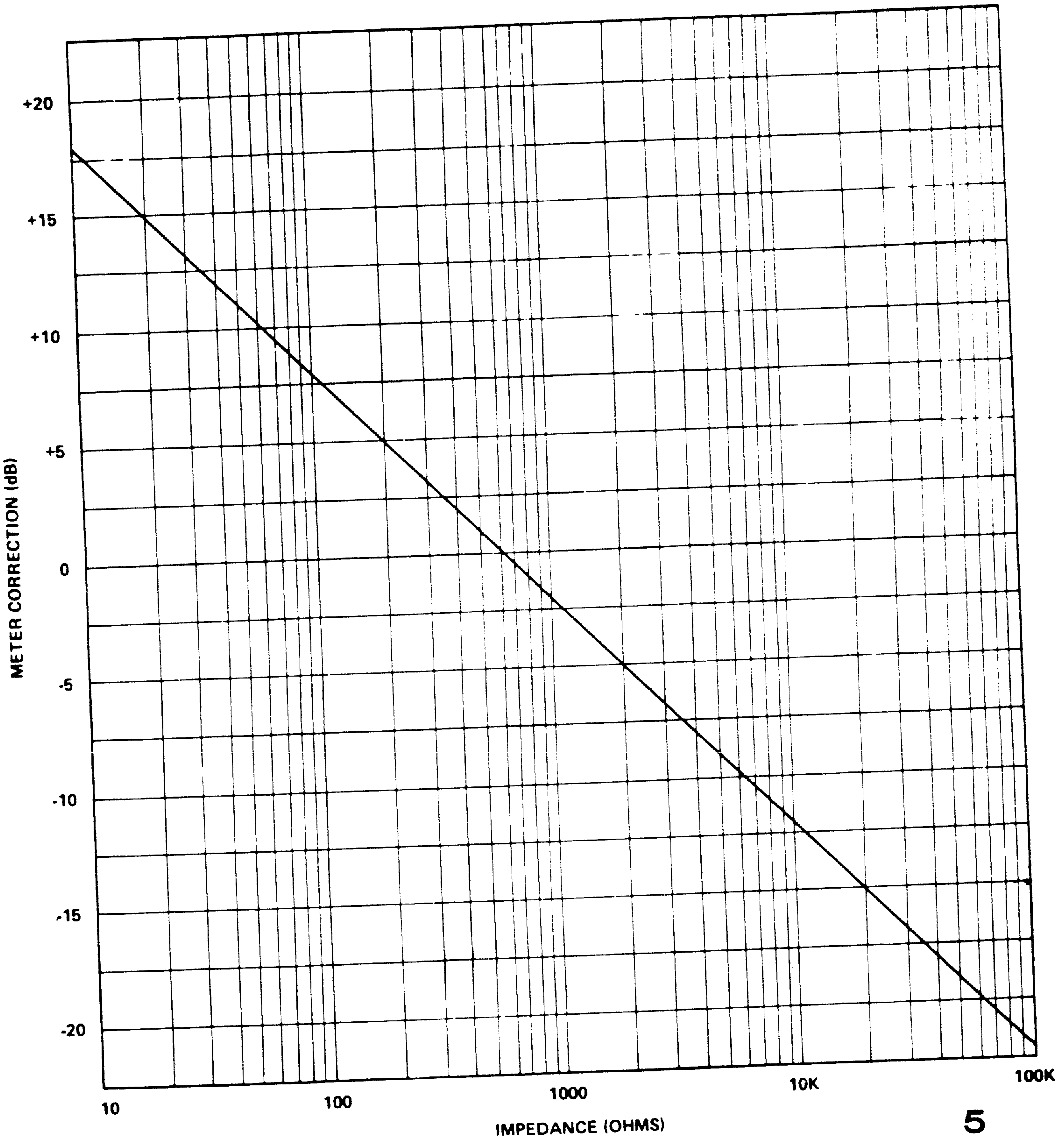


Figure 3. Meter Correction Graph

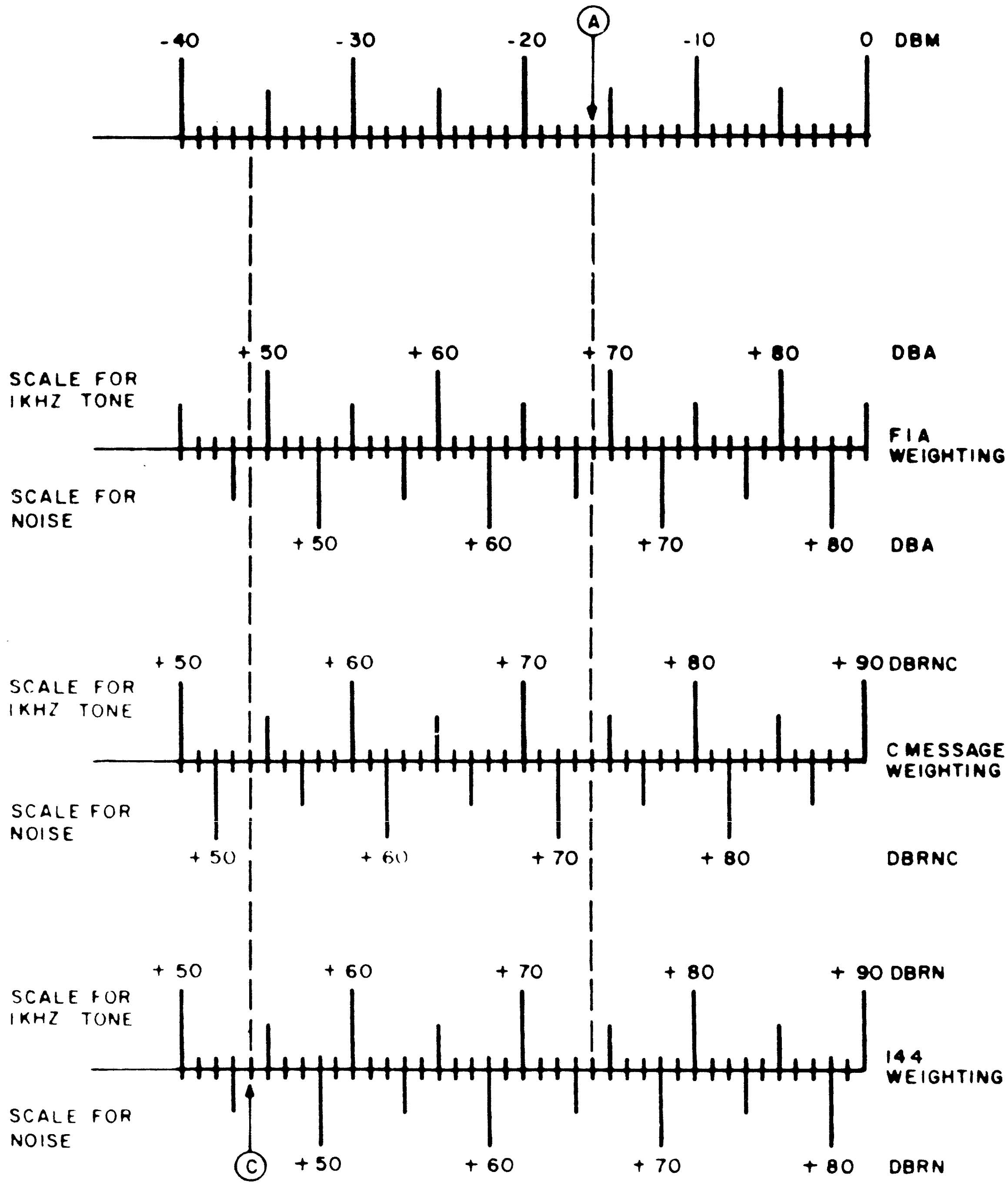


Figure 4. Nomograph for Conversion of Noise Units, 0 to -40dBm

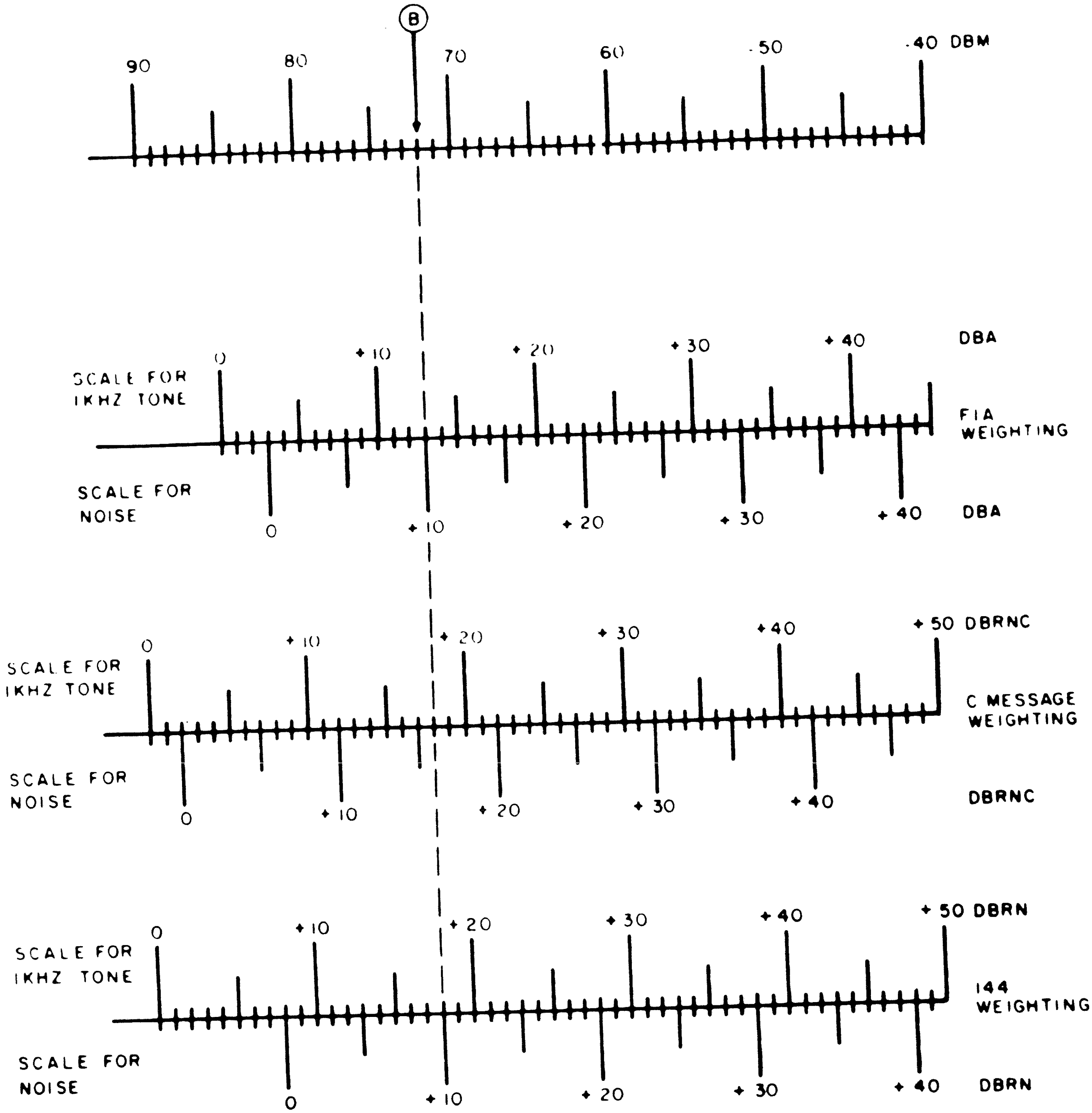


Figure 5. Nomograph for Conversion of Noise Units, -40 to -90dBm

APPENDIX 5. PRINCIPLES OF RF TRANSMISSION LINES

1. GENERAL.

This section covers basic principles of rf transmission lines. Consult commercial and military manuals devoted to transmission line theory for additional details.

2. ELECTRICAL TYPES OF LINES.

Transmission lines (feeders) convey rf energy from a transmitter to an antenna or from an antenna to a receiver. From an electrical viewpoint, there are two general types of lines.

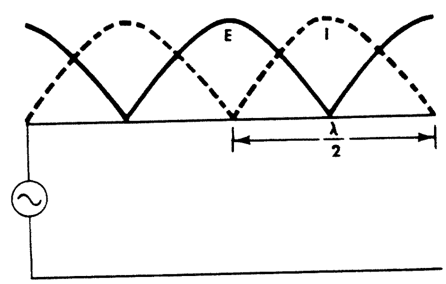
a. **Tuned lines** have standing waves and must be tuned or cut to resonance at the operating frequency.

b. **Matched lines** have no standing waves; they are terminated by the antenna or receiver in a resistance equal to the characteristic impedance (Z_o) of the line.

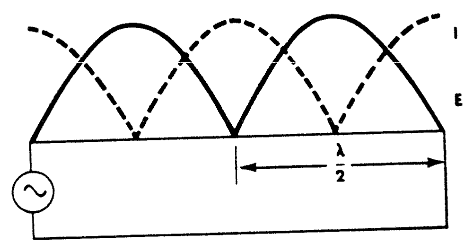
3. STANDING-WAVE RATIO.

a. In any line, the ratio of the current maximum (loop) to the current minimum (node) is called the standing-wave ratio (swr). This ratio is always identical to the ratio of the line impedance and the terminating impedance. Thus, if the transmission line has a 600-ohm impedance and is terminated by either a 72- or a 5,000-ohm resistance, the mismatch and the swr are 8.3 to 1 in either case. A measurement of the standing waves along the line gives an indication of the degree of mismatch present and can be used in the adjustment of matched transmission lines. Figure 1 shows, in part A, standing waves on an open-circuited line. In part B, the standing waves are shown on a short-circuited line. A high swr indicates that power which should be reaching the antenna or receiver is being radiated or dissipated by the transmission line. As an illustration of the effect of mismatch on swr, parts A and B of figure 2 both have a magnitude of 5 for the termination with relation to the Z_o of the line. If the standing-wave current shown is measured on one line at points B′ or C′ and on the other at points B and C, it will be found that the current at B′ and B is five times that measured at C′ and C. Therefore, the swr is 5 to 1, exactly the relationship that exists between the characteristic impedance of the line and the load resistance.

b. The importance of keeping the swr low in designing and maintaining communication antennas and transmission line systems cannot be overemphasized. The normal losses of line added to swr loss may make some low-power transmitting and some receiving systems unacceptable in reliability. Where it is necessary to have relatively long runs of solid-dielectric coaxial cable, the need to keep swr low becomes paramount. Tables and nomographs are provided in appendix 8 of this order to provide information relative to potential and actual loss that can be experienced with selection of certain types of line, increase of swr from inattention to maintenance requirements, dielectric deterioration, moisture leakage, and severe weather effects.



A. OPEN-CIRCUIT LINE



B. SHORT-CIRCUITED LINE

Figure 1. Standing Waves on Open-Circuited and Short-Circuited Lines

c. A term frequently encountered in standing-wave measurements is the voltage standing-wave ratio (vswr). This term expresses voltage maxima and minima on a transmission line. Swr can be expressed in decibels by use of the following relationship.

$$SWR_{dB} = 20 \log_{10} VSWR = 20 \log_{10} \frac{V_{max}}{V_{min}}$$

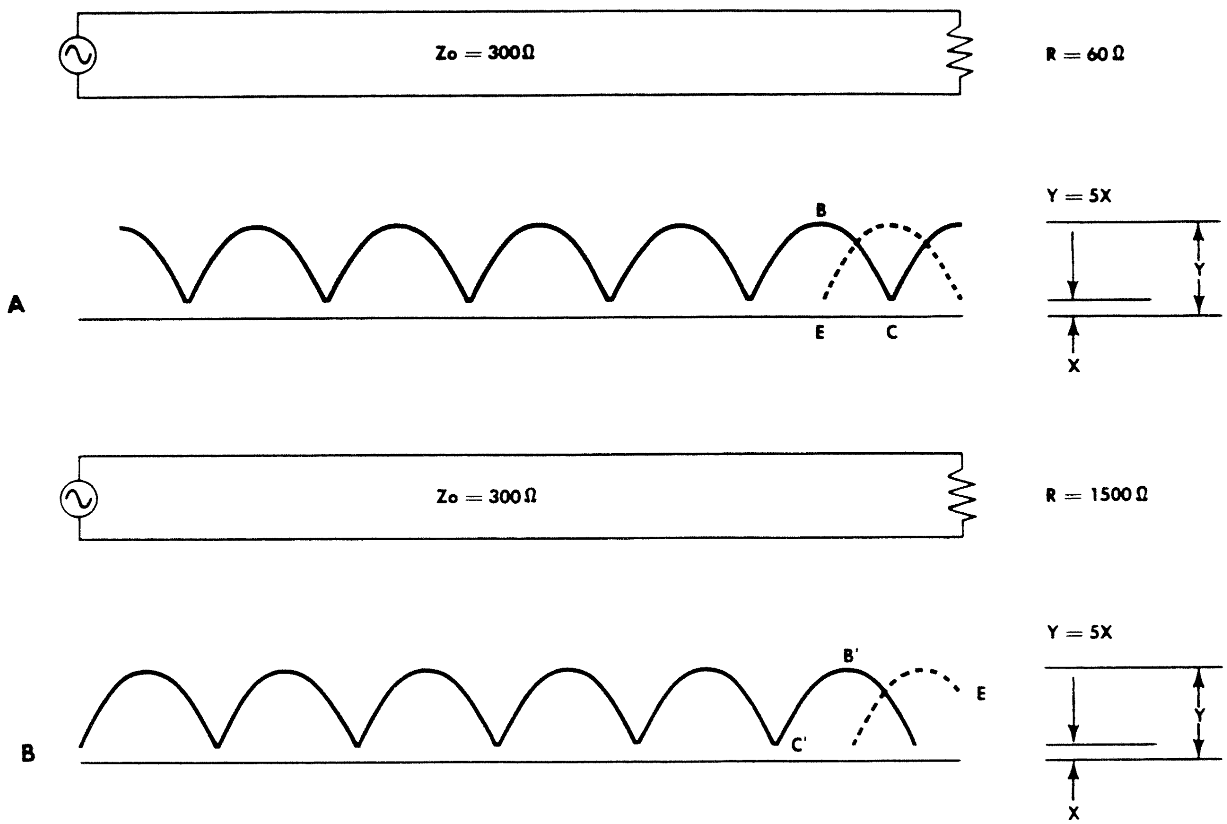


Figure 2. Relation of Mismatch to SWR

The general term swr, for the most part, is used throughout this order. Vswr is used when specifically addressing a measurement of voltage maxima and minima on a line.

4. TUNED LINES.

a. Tuned lines generally are used for multiband operation of an antenna. Obviously, if the line can be tuned to any frequency by a coupling device at the transmitter or receiver, then power can be introduced into or taken from the system antenna and transmission line at any frequency.

b. Tuned lines generally are connected to the antenna at the center or at one end. However, in an antenna that is several halfwaves long, the tuned lines can be connected at any point in the antenna that is a voltage or current loop. If the line is connected at any voltage loop (or at the end of the antenna), the termination has a high impedance, and voltage loops appear every half wavelength along the line. Conversely, if the line is connected at any current loop (or the center of a half-wave antenna), the termination has a low impedance, and current loops appear at the end of the line and every half wavelength along the line. From this can be determined whether a voltage or current loop appears at the transmitter end of the line. A parallel-tuned circuit should be used to resonate the system at a voltage loop and a series-tuned circuit at a current loop.

c. It is not necessary to have the line any exact length, inasmuch as the tuned circuit can compensate for a lot of deviation. However, it is best to have it as near as possible to some multiple of a quarter wavelength, since there are a few critical lengths that are difficult to resonate on particular frequencies. If difficulty is experienced in tuning the line, a few turns of wire added to each feeder line usually add sufficient length to permit tuning.

5. OPEN-WIRE LINE SPACING.

a. Between Feeders. The spacing between the two feeder lines must be a small fraction of the wavelength. A separation of 0.01 wavelength or less is desirable. At 20MHz the lines need not be closer than 6 inches (15cm). As the frequency increases, this spacing decreases, and other means should be used for transferring power to the antenna when this maximum spacing becomes so small that open-line construction is impractical.

b. Between Grouped Transmission Lines. If two or more transmission lines run near each other, the minimum spacing between the two lines should be at least 10 times the spacing between feeders. For example, with 8-inch (20cm) spacing between feed lines, transmission lines should be separated no less than 80 inches (200cm). Criteria for fixed signal installations are set at 8 feet (2.44m) horizontal and 4 feet (1.2m) vertical separation as minimum for open-wire transmission lines.

6. CHARACTERISTIC IMPEDANCE OF MATCHED LINES.

a. Open Wire. With an air dielectric, the characteristic impedance of a parallel-wire transmission line is given by the formula:

$$Z_o = 276 \log \frac{b}{a}$$

where Z_o is the characteristic impedance in ohms, b is the center-to-center spacing between the two feed lines, and a is the radius of the conductor. The quantities for b and a must be the same units of measure – inches, centimeters, etc. This formula is applicable to any parallel-wire transmission line having the majority of its separation formed of air.

b. Coaxial Lines. The characteristic impedance of an air-dielectric coaxial line is given by the formula:

$$Z_o = 138 \log \frac{b}{a}$$

where Z_o is the impedance in ohms, b is the inside diameter of the outer conductor, and a is the outside diameter of the inner conductor. The quantities for b and a must be in the same units of measure. This formula is correct for air dielectric and bead-supported coaxial cables. The characteristic impedance of solid insulated rf coaxial cables depends on the type of insulation used.

7. HARMONIC SUPPRESSION.

a. Tuned transmission lines generally permit a higher harmonic radiation than matched line systems, except when they are used with a broadband antenna. Pure inductive coupling from the transmitter to the transmission line usually reduces the harmonic radiation from the antenna system.

b. Harmonics usually are transferred to the antenna by capacitive coupling. Thus, it is desirable to reduce or eliminate any capacitive coupling between the transmitter and the transmission line. When using a link coupling to eliminate the harmonic transfer, the link coil should be coupled at the low-voltage point on the final amplifier tank circuit coil. This low-voltage point appears where the tank coil is bypassed to ground or at the center of a balanced circuit. In some cases, it may be necessary to ground the center of the link coil to sufficiently decrease the transfer of harmonic energy.

c. A Faraday shield can also be used to prevent excessive harmonic radiation from the antenna system. This shield is a comb of metal between the coupling coils. No electrical circuit, such as closed loops of wire, should be attached to any part of the shield, because the induced currents would cause heating of the shield and additional inductive losses. The shield is flat if it is used between two coils, the ends of which are coupled; it must be concentric and between the two coils if it is used with concentrically coupled coils. In either case, it can be made by winding wire (spaced its own diameter) on a flat or round form of heavy paper or other insulating material. Wire of any size from No. 14 to No. 22 American Wire Gauge (AWG) can be used. The winding should be painted with several coats of coil lacquer. When dry, the coil should be cut in a straight line parallel to its axis. One set of cut ends are then soldered to a straight piece of wire. The result is a comb-like formation of parallel wires, either flat or round, insulated from each other but metallically coupled at one end. The shield is placed between the tank and output coils and is grounded. The Faraday shield prevents capacitive coupling, but it has no effect on the normal magnetic coupling between the two coils.

8. OPEN-WIRE LINE REQUIREMENTS.

a. The minimum spacing becomes a factor where conductors may swing in the wind or become coated with ice. Mechanical strength rather than current-carrying capacity usually is the major factor to consider in selecting the gauge of wire for open-wire rf lines. Wire having low tensile strength cannot be stretched tightly enough without breaking under wind or icing conditions. Wire that is too large in diameter requires excessive sag, which makes it more susceptible to swaying in the wind (paragraph 9). A three-strand conductor (each strand No. 12 AWG) or its single-strand rf equivalent (No. 6 AWG) generally is used.

b. The lengths of the two electrical sides of the lines should be kept identical. Sharp turns should be avoided wherever possible. A necessary sharp turn should be made with jumpers that take a gradually curving path. The jumpers on opposite sides of the line must be identical in length and have the same spacing throughout their curve as does the transmission line. These length and spacing requirements are most conveniently met by twisting the transmission line to a vertical position just ahead of the turn, and returning it to horizontal position after the turn has been completed. The twists (or semi-transpositions) in the line must be gradual. After twisting the transmission line to a vertical position to make a bend, it is advisable to twist the line again in the opposite direction and for the same distance. This equalizes the capacitive unbalance introduced by the first twist, which places one conductor closer to the ground than the other.

c. The line spacing should be measured accurately and kept uniform. Any slight variation of line spacing may cause a point of impedance irregularity to be formed in the transmission line.

d. All wire connections should be well served and soldered. All connections should be either pour or dip soldered to prevent the uneven solder lumps and points that form when a soldering iron is used.

e. The supporting poles should be placed at varying distances from each other, with no two adjacent pole spans alike. Each insulator adds to the conductor a definite mass of conductive material in the form of tie wire and metal ends of the insulator. The variation of pole spans prevents the establishment of resonant sections in the lines by reflections from the various lumps of conductive material.

f. Special attention should be given to building entrance arrangements. Entrance to the building by the line must be spaced to maintain the correct impedance. Electrical continuity must be maintained through the building wall. Lightning protection should be designed and installed so that both wires of the line have identical circuits through the protective device. Electrical conductors must be prevented from grounding through the building walls in wet weather.

g. No connections to the line should be made that would result in different impedances to ground from each conductor. Each connection or tie wire on one side of the line should be duplicated in an identical manner and at exactly the same electrical point on the other side of the line.

9. SAGGING OF OPEN-WIRE SPANS.

Sag is the maximum departure of a wire from the straight line between the two supported ends of the wire. The common tendency is to pull small conductors too tightly and to leave excessive sag in large conductors. When the small wires are too tight, they may break in cold weather, or stretch, and thus reduce the cross-section size of the wire.

10. RIGID, AIR-DIELECTRIC COAXIAL LINES.

a. Rigid, air-dielectric lines have characteristic impedances ranging between 50 and 75 ohms. They have relatively low loss per unit length. Their unbalanced electrical characteristic makes them low radiators of spurious energy and therefore desirable when necessary to run several cables in proximity, as when feeding antennas in a multifrequency array. They lend themselves well to corrective matching by the sleeve or stub method, and they have high rf power capabilities. Fixed directional couplers or wattmeters can be built into these lines by using standard hardware supplied for the purpose, and they can be made moisture-proof with an insert gas (e.g., nitrogen) line pressure system. Figure 3 is a cutaway drawing of an air-insulated coaxial cable.

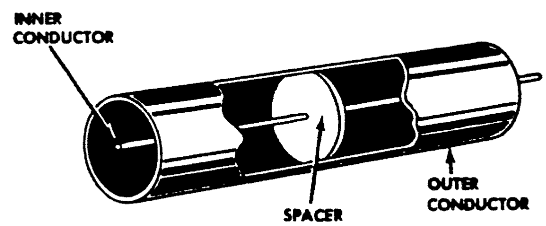


Figure 3. Sectional View of Air-Insulated Coaxial Cable

b. The rigid coaxial line is made of copper tubes that, for all practical purposes, cannot be bent. Assembly of these tubes is essentially a pipe fitting job requiring the necessary couplings, junctions, and terminal fittings.

c. Some cables of 7/8-inch (2.2cm) outside diameter or less are called soft-tempered cables and can be bent. These are essentially air-dielectric coaxial cables.

d. It is necessary that moisture be kept out of air-dielectric lines because any changes in the humidity of the air dielectric would give a corresponding change in impedance. To keep the lines dry, they are usually filled with dry air or inert nitrogen gas under pressure.

e. The larger sizes of air-dielectric lines are capable of transmitting considerable amounts of power.

11. FLEXIBLE, SOLID-DIELECTRIC COAXIAL LINES.

The most widely used coaxial line, or coax, is the flexible, polyethelyne, solid-dielectric coaxial cable. This cable is available in many types, diameters, and characteristic impedance. Losses of rf energy are higher in solid-dielectric cable than in air-insulated cable or open-wire lines. The dielectric is also subject to cold flow, a deteriorating process whereby the center conductor loses perfect concentricity with the outer metallic sheath. Periodic testing of installed and stored coaxial cable is necessary to ensure that its losses from age, water, and deterioration are not greater than the published loss for the particular cable in use. Foam-filled flexible or semiflexible coaxial cable provides less loss per unit length than the solid polyethelyne type. A trade name of one make of this cable is Foamflex. Figure 4 is a sectional illustration of a solid-dielectric cable.

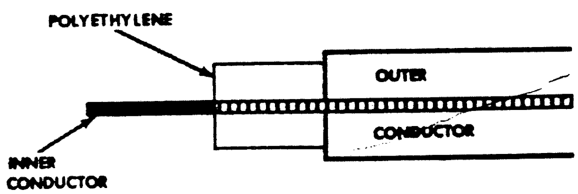


Figure 4. Sectional View of Solid-Dielectric Coaxial Cable

12. TWISTED-PAIR TRANSMISSION LINES.

The characteristic impedance of a pair of wires twisted around each other is approximately the same as the impedance at the center of a half-wave antenna (72 ohms). This provides a simple method of connection to this particular type of antenna. The losses in such a line, however, are greater than the loss in a comparable length of open-wire line. Since the line has an overall low impedance, the rf voltage in the line itself is relatively low, and the line is easy to insulate. For receivers, the twisted-pair line loss, up to several wavelengths, is unimportant because the loss in the line attenuates the signal and any rf noise picked up in the antenna system in the same proportion. Thus, the signal-to-noise ratio remains essentially unchanged. For transmitters, however, special low-loss twisted-pair lines having sufficient insulation to carry the rf power without breaking down should be used.

13. TRANSMISSION LINES AT VHF AND UHF FREQUENCIES.

At vhf and uhf frequencies, transmitters generally have low-power output, permitting the use of solid-dielectric coaxial cables for transmission lines. In the vhf and uhf bands, 50- to 70-ohm, solid-dielectric, flexible coaxial cable (or foam-dielectric cable) ordinarily is used to feed elevated antennas. However, the use of closely spaced open-wire lines is also possible. For high power in the lower vhf band, rigid air-dielectric coaxial lines may be installed.

14. COUPLING AND MATCHING.

a. Feeders are connected to antennas or receiving equipment by coupling and matching arrangements. These arrangements, or circuits, are considered as part of the transmission line system. Such elements are essential to maximum transfer of power between equipment and antenna.

b. Connecting an antenna to equipment generally involves the use of a transmission line that may be several wavelengths long. Proper coupling at the antenna end and the equipment end of the line is necessary for efficient operation.

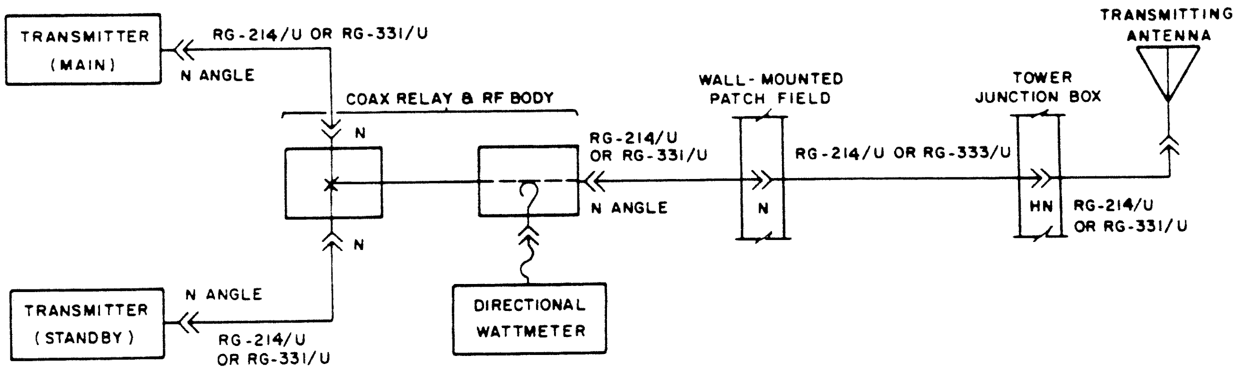
c. At the antenna end, the characteristic impedance of the line should be as nearly equal as possible to the input impedance of the antenna to avoid reflection of energy and consequent standing waves. Excessive reflections at this point can cause high line losses, spot heating, flashover in the line when transmitting, and detrimental echo and intermodulation effects in multichannel communication circuits. The adequacy of the match is determined by a measurement of the swr along the line.

d. In the case of a transmitter, the final amplifier generally is tuned and coupled to the line so that a maximum of power is transferred, consistent with the power rating of the amplifier. Ideally, the procedure consists of tuning out any amplifier output reactance and in matching resistances. Actually, some reactance is usually developed in the line as a result of slight imperfections in the antenna match, in which case the transmitter tuning includes the introduction of reactance of opposite sign to cancel that appearing in the line.

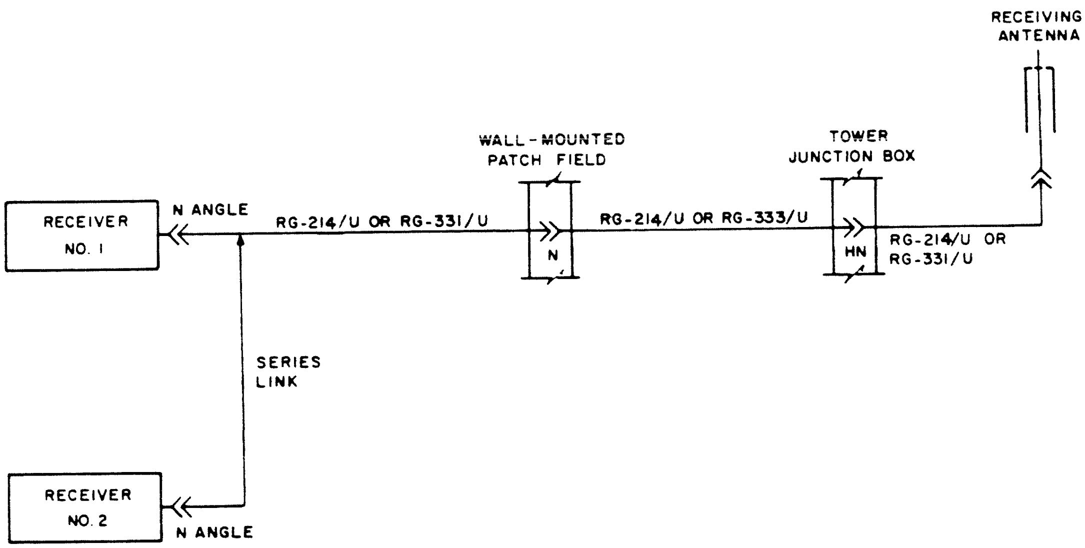
e. Connecting transmitting and receiving equipment to an antenna usually involves interconnection via a number of different antenna cable types and connectors. When main and standby transmitter switching and series receiver multipling are requirements of the facility, a further complication is introduced, by use of a transfer rf relay in the transmitter case and by a series coaxial arrangement or transfer relays in the receiver case. Further requirements may include patching in the facility. An antenna junction box on a tower accommodates final connection to the transmitter and receiver antennas. Figure 5, part A, is a simplified diagram of main and standby transmitter connections showing cable and connector types. Part B of the figure shows receivers that are series connected. Main and standby relays are also used for receivers that are not series connected.

15. TRANSMITTER COUPLING.

Several types of transmitter coupling (and tuning) circuits are shown in figure 6. They include inductive, direct, pi-section, and link coupling. One of these circuits may be incorporated in a transmitter design according to the relative importance of such items as number of extra components, number of controls, ease of adjustment, and suppression of harmonics. The signal bandwidth is ordinarily such a small percentage of the carrier frequency that, except for special systems, any type of coupling yields a sufficiently flat characteristic over the required band. Tuning methods are described in the manual for the particular radio set incorporating the method of coupling. The coupling system used in a transmit-



A. TRANSMITTER-TO-ANTENNA SYSTEM



B. ANTENNA-TO-RECEIVER SYSTEM

Figure 5. Complete Transmitter-and-Receiver-to-Antenna Transmission System

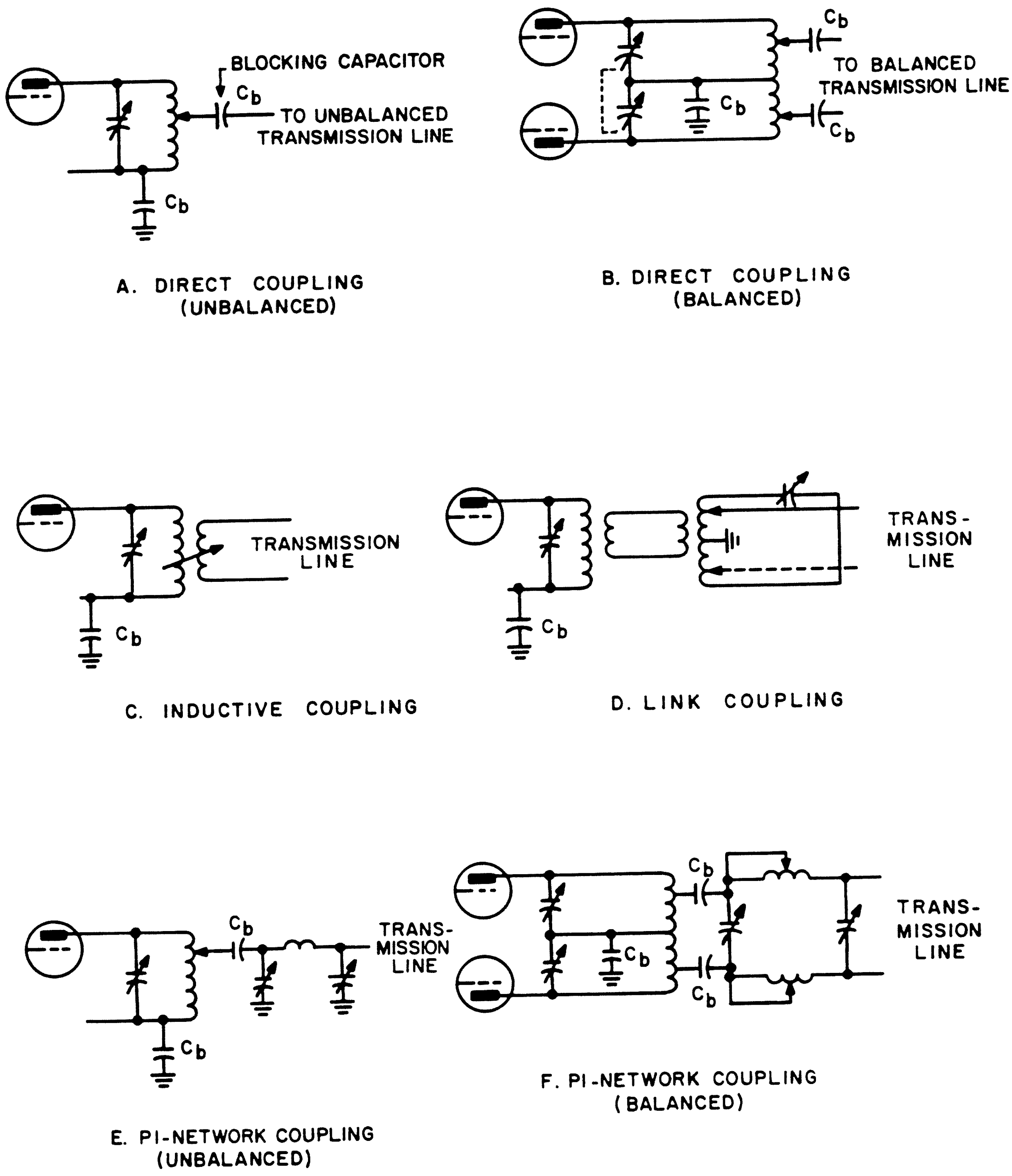


Figure 6. Transmitter Coupling Arrangements

ter should be determined before selecting the type of transmission line for use with that transmitter.

16. INDUCTIVE COUPLING.

a. Inductively coupled circuits (part C of figure 6) are better than the direct coupled circuits if an unbalanced tank coil feeds a balanced transmission line. Line unbalance caused by the final tank circuit may be avoided in this manner.

b. The transmission line coil, generally called the antenna coil, should be coupled to the final tank coil so that the center of the antenna coil is near the electrical center, or rf ground point, of the final tank coil.

17. DIRECT COUPLING.

a. The direct-coupled transmission lines (parts A and B, figure 6) are most useful when the final amplifier plate supply is series fed to the plate. The capacitors are used to keep the final plate voltage off the antenna system. They should have a voltage rating higher than the maximum plate voltage used, and they should have a comparatively high capacity. The current rating should be higher than any current normally encountered.

b. A single-wire transmission line is tapped onto the coil (part A of figure 6) at different points on a trial and error basis until normal full-load plate current is drawn with the final amplifier tuned to resonance.

c. A two-wire transmission line (part B of figure 6) is tapped onto the final amplifier tank coil symmetrically about the center of the rf ground point of the coil. The taps are adjusted to make the final amplifier draw normal, full-load plate current when tuned to resonance.

18. PI-NETWORK COUPLING.

The pi-network types of coupling shown in parts E and F of figure 6 are low-pass filters. These networks are capable of coupling two impedances that have a large difference of reactance. The variable capacitors in the transmission line circuit may be from 100µF to 1,000µF each, depending on the operating frequency. The spacing between the plates of these capacitors should generally be at least half that of the final tank capacitors.

19. LINK COUPLING.

Variable link coils may be used at either end of the link. Link coils consist of two or three turns of wire coupled to the amplifier tank coil at a low voltage point and to the antenna coil at the electrical midpoint. See figure 6, part D.

20. RECEIVER COUPLING.

When matching an antenna and line to a receiver, the emphasis is not only on transferring a maximum of power, as it is at the transmitter, but is also on improving the signal-to-noise ratio and avoiding interference. Some communication receivers have input-tuning adjustments to cancel the line reactance. However, the objective is to improve response at the desired frequency and reject other frequencies more effectively, thus increasing the selectivity. With only reactive compensation, the resistances of the line and the receiver are usually unmatched. The reflection loss caused by this mismatch is tolerable in most cases since a cable generally is used that has an impedance approximately the same as the input impedance of the receiver. The loss in efficiency is no disadvantage where external noise is the controlling factor since both signal and noise are attenuated equally. In many receivers with transformer step-up at the input, a mismatch is deliberately designed into the input circuit to improve the signal-to-noise ratio from equipment noise alone, provided the echoes reflected over a long connecting line are not excessive. Methods of coupling more than one receiver to a single antenna are covered in appendix 10.

21. MATCHING ANTENNA TO LINE.

When connecting an antenna to a transmission line, the line can often be selected to match the antenna input impedance. For example, a 600-ohm open-wire line would be a fairly good match for a three-curtain rhombic antenna, or a 300-ohm line would suffice for a two-wire, half-wave, folded dipole. When direct matching is not practical, as with very low or very high impedance antennas, or where cables that are manufactured in a limited number of sizes are used, some form of matching device is necessary. Usually, impedance-matching transformer systems are connected in series with the line, and auxiliary tuned systems are connected in parallel with the line.

22. ANTENNA-COUPLING TRANSFORMERS.

a. Antenna-coupling transformers are the common, coil-type rf transformer and may be used to couple an antenna to an rf transmission line or a transmission line to a radio set. They permit impedance transformation for matching purposes and balanced-to-unbalanced connections. Most of these units are made so that one side of the transformer must be operated balanced.

b. Some standard antenna-coupling transformers were designed to give no more than a 2dB loss from 6 to 20 MHz. Later models of these transformers are designed for a loss of no more than 2.5dB from 2 to 30 MHz. These standard transformers are intended for use with receiving installations, and have low power-handling capabilities.

c. In general, antenna-coupling transformers are designed for matching 200- or 600-ohm balanced antennas to 50- or 70-ohm unbalanced coaxial cable. Optional connections usually are available on the high-impedance side of the transformer for use with either 200- or 600-ohm antennas. Some models have 250- and 700-ohm connections on the high-impedance side of the transformer.

d. There is usually a dc path across the transformer through rf chokes. This permits dc testing of the antenna and termination resistance.

23. MATCHING LINE SECTIONS.

Several types of matching line sections have been designed for construction in the field. The more common types are the delta match, the tapered line, and the quarter-wave matching line.

a. The delta match (part A of figure 7) generally is associated with a delta-matched doublet antenna.

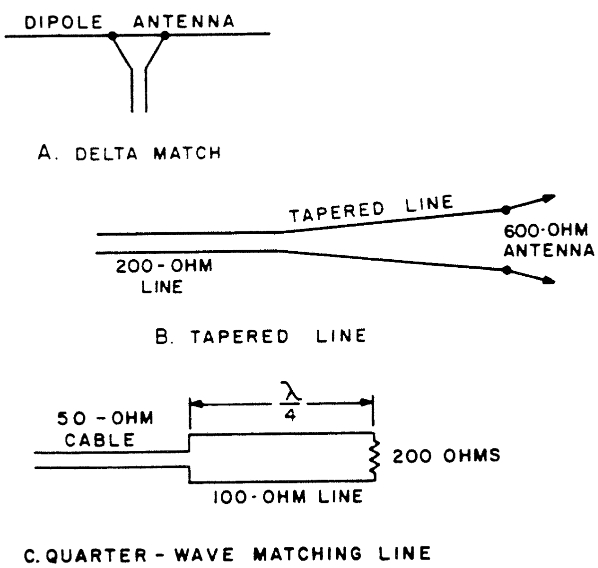


Figure 7. Open-Wire Impedance-Matching Trans-

b. A tapering transmission line with a progressively increasing characteristic impedance may be used to feed an antenna at a moderately high impedance point. For example, a tapered line (part B of figure 7) can be used to connect a 200-ohm transmission line to a 600-ohm antenna. The gradual taper of the line changes the characteristic impedance slowly enough so that reflections are negligible.

c. A quarter-wave matching line (part C of figure 7) can be inserted between two segments of line. This matching device is based on the principle that a transmission line exactly one-quarter wave long (or any odd multiple thereof) can transfer rf energy to another transmission line of any impedance with none of the detrimental effects of mismatching. The quarter-wave matching line is designed to have a characteristic impedance equal to the square root of the product of the impedances at the ends. Thus, a 200-ohm load can be matched to a 50-ohm cable if, at the end of the cable, a quarter-wave length of line or cable having a characteristic impedance of $\sqrt{200 \times 50}$, or 100 ohms, is inserted. Usually, it is necessary to tune out any antenna reactance before including the quarter-wave transformer. Changing the antenna height may sufficiently alter the antenna input impedance to aid in securing a good match. This method limits the use of the system to a single frequency.

d. Coupled sections and reentrants are open-wire matching methods frequently used when minor corrections are needed in impedance match, or when multifrequency systems of feeders need to be tuned independently to a common antenna.

e. Coaxial line matching sections or balance converters are shown in figure 8.

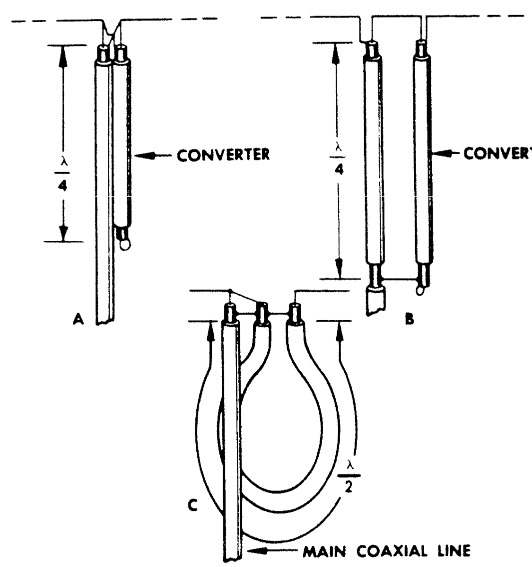


Figure 8. Coaxial Impedance-Matching Transformers

24. HALF-WAVE LINES.

The half-wave line is based on the principle that the impedance of a resonant line with low loss is the same at successive half-wave intervals along the line. Thus, similar impedances can be matched at a particular frequency at any one of these half-wave points, regardless of the characteristic impedance (Z_0) of the transmission line. For example, to connect a receiver with a 300-ohm input impedance to a 300-ohm antenna, it is possible to use a coaxial cable of any Z_o if the length of the cable is exactly one-half wave or a multiple thereof. Any length of 300-ohm line may be used from the antenna to some point close to the receiver, and then connected to a length of coaxial cable exactly one half-wave long (or multiple thereof) for passage through building walls or interior ducts to the receiver. This system limits the antenna, transmission line, and receiver to use on only one frequency. Therefore, the use of half-wave lines for matching purposes is limited by operational considerations.

25. MATCHING STUBS.
Another method of matching impedances is to use a tuned, quarter-wave, matching-section stub line (figure 9). The exact length of the matching section and the position of the line taps must be determined experimentally because they depend on the impedance of the transmission line, as well as the antenna impedance at the point of connection. The tuning stub usually can be used to match an antenna to any line impedance.

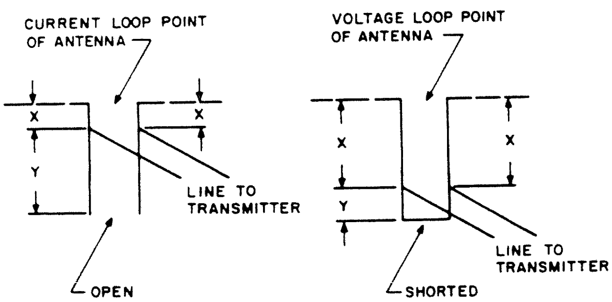


Figure 9. Stub-Line Impedance Matching

a. The approximate length of a quarter-wave matching stub is calculated from:

$$L(ft) = \frac{240}{f(MHz)}$$

This formula gives an approximate length, and the stub should be tuned after it has been installed.

b. Approximate values of distances X and X plus Y (figure 9) may be determined from the curves in figure 10. These curves apply only to 600-ohm transmission lines. Trial and error adjustment for exact matching to the terminating impedance is required after the matching stub is constructed according to these curves.

26. BALANCED-TO-UNBALANCED MATCHING SYSTEMS.
When unbalanced transmission lines connect to balanced-type antennas, such as a coaxial line to a dipole antenna, the dissymmetry causes extraneous currents along the outer surface of the cable or line. These currents are present, even though the impedances are apparently matched, and they cause radiation that may be undesirable. They can be minimized by the use of special balanced-to-unbalanced networks called baluns.

a. A method of constructing a balun for coaxial cables is shown in part A, figure 11. A concentric cavity, a quarter wavelength long, is placed around the cable sheath at the feed point. The lower end is short-circuited to the sheath so that the upper end presents a high impedance. Any currents that might flow along the outer surface are therefore minimized.

b. Another common type of balun that effects the balance-to-unbalance transformation and also affords a 4-to-1 step-up in impedance, is shown in part B of figure 11. It includes a half-wavelength line (usually coaxial) multipled to the output of the feed line. The output voltage between the two inner conductors is balanced. However, because the voltage between the inner conductor and sheath at the end of the half-wavelength line is equal and opposite to that at the input, a 2-to-1 increase in voltage between respective inner conductors is obtained at the output terminals. As in an ideal transformer, this voltage increase results in a fourfold increase in impedance.

27. INTERFERENCE SUPPRESSION.

a. Coaxial bandpass cavities may be inserted in transmission lines for the purpose of suppressing or eliminating rf interference. One of these cavities placed between the antenna and receiver will improve receiver selectivity immensely. The cavity will reduce or minimize off-channel interference that otherwise would pass through to the receiver's front end and cause desensitization, spurious responses, or intermodulation interference. When tuned to a transmit frequency and installed between a transmitter and associated antenna the cavity will reduce spurious and harmonic radiation or transmitter sideband noise that could get into nearby receivers and degrade performance. The bandstop cavity is the opposite of the bandpass cavity. It is tuned to reject unwanted frequencies or a band of frequencies quite close to the wanted frequency or, if necessary, several megahertz away. Notch filters can be added in series to obtain additional attenuation to an interfering frequency. Insertion loss of the cavities must be added to the other system losses in computing service volume coverage capabilities.

b. Ferrite isolators may be inserted in transmitter antenna lines for the purpose of suppressing or eliminating rf interference. Within the rated bandwidth of the ferrite isolator up to 30dB of isolation from other transmitters can be provided to reduce or eliminate intermodulation product generation.

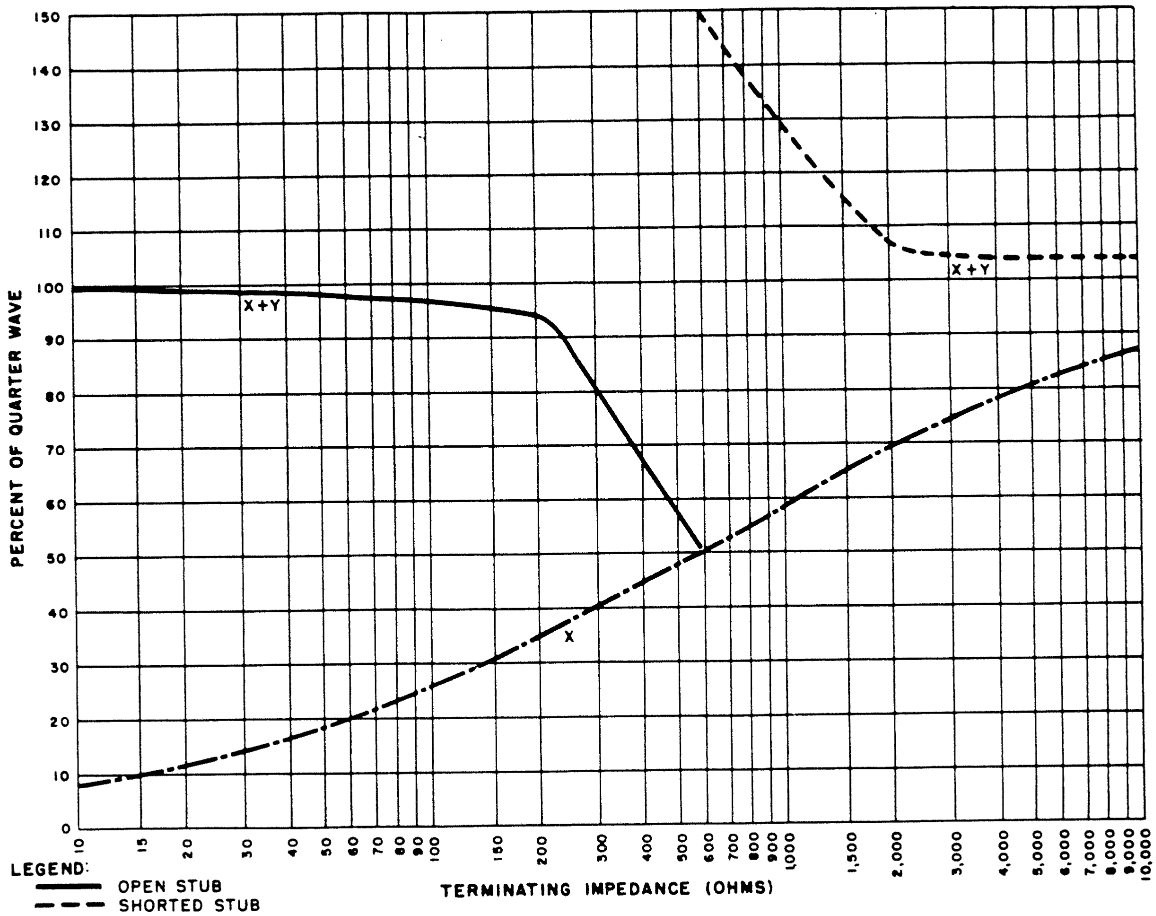


Figure 10. Graph for Quarter-Wave Stub Length and Positioning

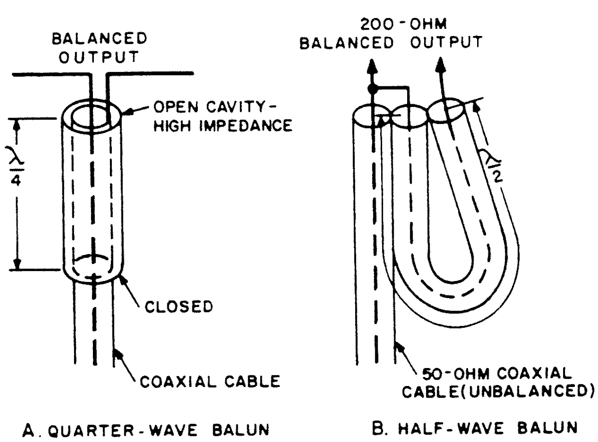


Figure 11. Quarter-Wave and Half-Wave Balun Arrangements

APPENDIX 6. PRINCIPLES OF ANTENNAS

1. GENERAL.

This section covers basic principles of antennas. For theory of antennas in greater detail, consult available antenna handbooks and manuals, both military and commercial.

a. An efficient antenna smoothly transfers power from one transmission medium such as a wire circuit to another medium such as surrounding space, and vice versa. On the wire side of the circuit, the usual wire network conditions of impedance match and low inherent loss must be satisfied. The antenna must launch the energy into space with little loss of power and usually with the added requirement of directing the energy in the proper directions. Essentially, the antenna is a wire circuit termination of special size and shape, so placed as to perform these functions efficiently.

b. A short length of wire energized with a high-frequency voltage is a simple form of antenna. The current flowing along its length is the source of the radiation, with the moving electrons producing the radio wave, or field, that reaches out to great distances. Conversely, the same kind of wire, when exposed to a radio wave, has a voltage induced into it and produces a potential across an associated resistance. Thus the wire delivers the energy collected from space to a conventional radio receiver. Figure 1 shows the basic forms of conductor antennas.

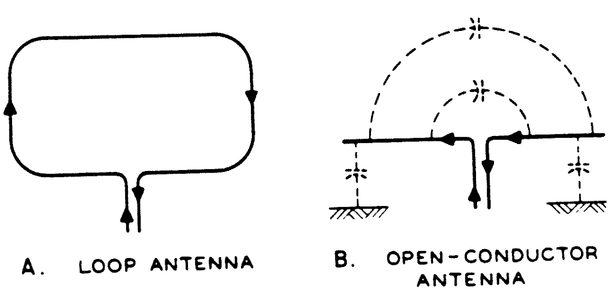


Figure 1. Basic Forms of Conductor Antennas

2. ELECTRICAL CHARACTERISTICS.

The following antenna characteristics are important in the design of a facility.

a. **General physical characteristics:** size, construction requirements, and kind of site required.

b. **Directional properties:** suitability for the kind of radio path proposed, such as ground wave or sky wave, and the distance involved.

c. **Polarization:** For groundwave use, antennas on the same circuit at both ends of a radio path should have similar polarization.

d. **Mutual interference:** approximate antenna patterns and separation distances required to prevent mutual interference and intermodulation.

e. **Gain:** need not be known separately in groundwave computations if the overall efficiency of the radio set is known. For computations of skywave paths, the gain must be known, because it is one of the limiting factors in the computations.

f. **Matching:** antenna impedance and balance to ground when matching the antenna to the radio set or the rf transmission line.

g. **Positioning:** This depends on whether the antenna must be close to the radio set or whether it will work properly with a transmission line. In general, antennas much shorter than a quarter wave must be close to the set or a coupling network.

h. **Grounding:** methods of grounding at radio frequencies and protection against high voltage.

3. RADIATION PATTERN.

a. The distribution of the radiated field in space depends upon the current distribution in the antenna and the angle from the antenna. A short, straight, energized conductor gives no evidence of current flow when viewed at its end. Therefore, the radiated field in either end direction is essentially zero. At progressively greater angles from the axis of the conductor to a line perpendicular to the conductor, the current appears in progressively greater perspective so that the intensity of the radiated field becomes increasingly stronger. The maximum current and radiated field is reached at right angles to the conductor. This radiated field is illustrated in figure 2. The thickness of the lines in part A of this figure represents the relative strength of the field.

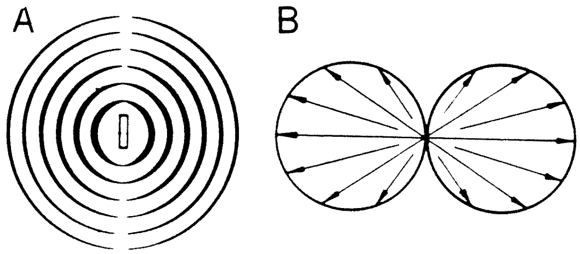


Figure 2. Radiated Field from a Short, Straight Conductor in Free Space

b. Each antenna has its own unique pattern in free space. The arrows in part B of figure 2 are proportional in length to the radiated field strength. The line around the arrowheads in this case describe a figure eight, which is the indicated radiation pattern of this particular antenna. This pattern represents only the radiation field not the ordinary inductive field. The inductive field around antenna is negligible beyond a large fraction of a wavelength from the conductor and does not enter into radio propagation.

c. The pattern in part B of figure 2 has been represented in one plane only. Since the aspect of the short, straight wire is the same in all other planes passing through its length, the same pattern is obtained in all such planes. Thus, the field measured at points on any circular path in a plane perpendicular to the wire is constant in value. The complete radiation pattern, therefore, is a three-dimensional figure, somewhat like a doughnut (figure 3). The general method of illustrating a radiation pattern, however, is in a cross section of the full pattern, showing only one particular plane.

d. As the straight wire is shifted or rotated in space, the radiation pattern moves with it. For example, a vertical wire radiates a uniform field in all directions in the horizontal plane and, therefore, is adaptable to mobile or broadcasting service where broad area coverage is required. This field is vertically polarized. Conversely, a horizontal conductor radiates mostly in the transverse vertical plane and, therefore, is useful for high-angle skywave transmission. The polarization in any direction is perpendicular to the radial line of radiation.

e. The pattern for a square loop antenna can be deduced from the combined effects of the currents in the sides. In a line perpendicular to the plane of the loop, the equal and opposite currents in the opposing sides of the loop result in a cancellation of the field. In the plane of the loop the fields from opposite sides do not cancel because of the difference in phase of the two fields. The field actually attains a maximum in this plane with the result that a doughnut shape is again obtained for the overall pattern. In the plane of the loop, the field is polarized in a direction tangential to a circle drawn from the center of the loop. The loop antenna is used mainly in direction-finding and homing equipment.

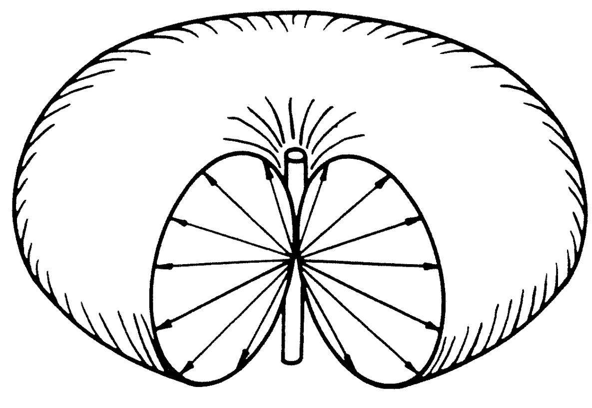


Figure 3. Three-Dimensional Nature of Radiation Pattern

f. A narrow, elongated loop energized at the midpoint of one long side has the appearance of a dipole folded back on itself and is called a folded dipole. When the sides are a half-wave long, the standing waves of currents in the two sides act in phase to develop a radiation pattern similar to that of the simple half-wave dipole.

g. From the preceding subparagraphs it can be seen that the shape of the antenna, the length of the individual sides or conductors in the antenna, the position of the conductors in relation to the ground, and other less specific factors all affect the exact radiation pattern produced from any particular antenna.

4. EFFECT OF RADIATION PATTERN ON SIGNAL INTELLIGIBILITY.

a. Signal intelligibility at the receiver input terminals is affected by the effects of the propagation path on the transmitted signal and by the patterns of the transmitting and receiving antennas. It is difficult to separate the two effects; one hinges on the other. For example, a wave of constant field strength may vary in its angle of azimuthal arrival within the limits of only a few degrees. If the receiving antenna has a pattern that is too sharp to respond uniformly over the angle of azimuthal deviation, the receiving antenna thereby introduces signal variation. If the receiving antenna has a deep null in its pattern and the arriving wave swings, the receiver will register a deep fade that may not have been present in the arriving wave, but which must be assigned to the receiving antenna pattern. If azimuthal variation is a factor on a particular circuit, then the ideal receiving antenna azimuthal pattern should be uniform over the range of possible angles of signal arrival and have zero response in all other directions.

b. What is true in the azimuthal plane is true in the vertical plane as well. There may be several wave groups arriving simultaneously at different vertical angles, although one group will dominate in intensity from movement to movement. Under these conditions, the receiving antenna will pick up, in effect, a single wave that is constantly changing its angle of vertical arrival. If the field strength of the arriving wave is constant but changing in angle, the vertical pattern of the receiving antenna, if nonuniform in response over the range of arrival angles, introduces signal variations as the signal comes in on different portions of its pattern. If the range includes a null in the antenna pattern, the receiver input terminals would register a very deep fade in the signal. These effects due to antenna response occur in many instances, and the signal itself also varies over a considerable range of values. When the horizontal and vertical angles of arrival correspond to directions of minimum antenna response simultaneously with a minimum arriving signal strength, the signal at the receiver input terminals may be far below the noise level and produce an interval of unintelligibility. These effects combine, and the signal at the receiver terminals undergoes a wide range of variation from moment to moment.

c. Another problem arises when more than one wave group arrives in the vertical plane with different time delays along each of the arrival paths. The resulting phase difference causes signal distortion even when the signals are strong. The delay is characteristically greater as the angle of arrival becomes higher, since each wave traverses a longer path. Wave interference between the different wave groups at the receiving antenna causes fading of the signals due to the delays.

d. On some propagation paths there is sufficient angle between the multipath wave arrivals so that the vertical pattern of the receiving antenna can select one and reduce or suppress the others. The shorter the circuit, the more likely it is that substantial angular difference in wave arrival will exist, including the effect of angular changes due to changes of layer height, thus permitting selective reception of one dominant wave group. On long-haul circuits, however, two or three orders of hops may arrive at so nearly the same angle that angular selection is impractical. Angular selection would involve an extremely sharp antenna pattern that would cause deep fading of the received signal when the wave-arrival angle varied. In such a case, there is no possibility of improving the intelligibility of the signal by this method. If multipath delays cannot be eliminated, there is little advantage to increasing transmitter power to improve signal intelligibility.

e. The transmitting antenna radiation pattern also is important. If it were possible to radiate all the power at the one optimum vertical angle that gives the best transmission path, there would be relatively little radiated at the angles that give rise to multipath transmission. The angle of departure for a given wave path is roughly the same as the angle of arrival at the receiving end of the path. It will usually be of value, therefore, to transmit less power at the undesired angles if one is trying to eliminate certain wave groups in order to improve intelligibility at the receiver. When the transmitting and receiving antennas are complementary, with maximum responses at the most favorable wave angles and relatively low responses at all other angles, it is possible to improve operating margins by using greater transmitting power.

f. Considering the above-mentioned factors, it is apparent that antenna gain may be a secondary consideration in the design of an antenna. The primary objective is to produce the most favorable radiation pattern in both vertical and horizontal planes, so as to minimize multipath and lobing difficulties. Too much directivity in the antenna pattern may be as unsatisfactory as insufficient directivity. Using random patterns or patterns not expressly designed for the desired service can give poor results.

5. GENERAL DIRECTIONAL REQUIREMENTS.

a. Antennas for use in broadcasting or in mobile net operation should not be sharply directional. Antennas for transmission between two fixed points should be as directional as possible.

b. In general, antennas for skywave transmission (or reception) should differ in their vertical directional patterns from those used for groundwave transmission. For groundwave transmission, antennas should have good radiation patterns along the ground. For short-distance skywave (200 miles (320km)) or less, the greatest radiation should be almost vertical. For medium-distance skywave (200 to 500 miles (320 to 800 km), somewhat lower angles are required. And for long-distance skywave (over 500 miles (800km)), still lower angles of radiation are necessary.

c. At high frequencies, antennas with satisfactory patterns for groundwave transmission include vertical whips, mast antennas and towers, T-antennas and other top-loaded verticals, wave antennas, and vertical half rhombics.

d. Antennas with good patterns for short-distance skywave include half-wave horizontals at heights above ground that are not more than a quarter wavelength at the operating frequency. Sloping-wire, half-wave antennas are also usable for the short-distance sky wave, if the slope is not too steep. The poorest type of antenna for this transmission method is a short vertical whip.

e. Antennas with good patterns for long-distance skywave include suitably designed rhombics, half-wave horizontal dipoles at heights between one-half and one wavelength, and vertical mast or tower antennas.

f. Skywave distances between 200 and 500 miles (320 and 800 km) are transitional. Half-wave horizontal dipoles a quarter wavelength above ground or up to a half wavelength above ground, for 500 miles (800km) are good.

6. STRENGTH OF FIELD.

a. The strength of the radiated field from an antenna is determined by the current flowing in the antenna wire and the length of the wire. When the circuit is resonant, that is, when the reactance of the wire at the frequency of the rf current is zero, the current flow in the wire is at a maximum. The shortest length of wire resonant at a particular frequency is the length that will just allow the rf current to travel from one end to the other and back again in the time required for one complete rf cycle. Radio energy travels at the speed of light, 300,000,000 meters per second. Thus, the distance covered by the rf current in one complete rf cycle is:

$$\lambda = \frac{300,000,000}{f}$$

where f is the frequency in hertz, λ is the wavelength in meters. Therefore, the shortest resonant wire is a half wave long, since the energy must traverse the wire twice.

b. A more useful formula that has been derived from the above formula to give the length of a half wave in space at any frequency is:

$$L = \frac{492}{f}$$

where L is in feet, f is in MHz.

For metric dimensions, the half-wave, free-space length can be calculated as follows.

$$L = \frac{150}{f}$$

where f is the frequency in MHz, L is the length of the half-wave dipole in meters.

c. Several factors affect the electrostatic capacity of an antenna wire. This capacity is higher than normal because of the dielectric effect of insulators at the ends of the wire antenna supports, guy wires, and other nearby objects. This is called "end effect." Each installation will have a different capacity deviation. A good average deviation is 5 percent less than the length of a half wave in free space. The formula for finding the physical length of a half-wave antenna is:

$$L = \frac{468}{f}$$

where f is in MHz, L is in feet.

NOTE: This formula does not apply to antennas longer than a half wavelength.

7. ANTENNA RESISTANCE.

Energy supplied to an antenna is expended in two forms, radio waves and heat losses. The useful part is the radiated energy in the radio waves. The formula for dissipated power (P) is:

$$P = I^2R$$

where R is the resistance, I is the current. In computing the power dissipated by an antenna in the form of radiation, R is an assumed resistance that would if it were actually present, dissipate the amount of power that is radiated. The total power is found, then, by combining this theoretical radiation resistance with the actual resistance in the antenna wire itself, the insulators, guy wires, etc. Thus, the total power dissipated by an antenna is expressed by:

$$P = I^2 (R_r + R)$$

where R is the real, or ohmic, resistance of the antenna and R_r is the radiation resistance.

8. INPUT IMPEDANCE – RADIATION RESISTANCE.

a. Lengthening a straight conductor from very small dimensions up to slightly over a half wavelength does not alter the radiation pattern appreciably. However, it does affect the input impedance, that is, the ratio of the input voltage and current. A short center-fed conductor has a large reactive component and acts as a leaky capacitive element. The inductive reactance increases as the wire length increases and eventually counteracts all the capacitance, so that only a resistance appears. This occurs when an isolated conductor is about a half wave long. Such a resonant condition is obtained at exactly one-half wavelength for an infinitely thin conductor, but occurs at lengths that are a few percent under a half wavelength for conductors of practical thicknesses. Resonance also occurs at every odd multiple of a half wavelength.

b. At the half-wave resonant length, the input impedance of a very thin, lossless, center-fed antenna, is a pure resistance of about 73 ohms. This input resistance usually becomes less as the conductor thickness is increased. However, measurements generally do not show consistent results. In some instances, the resistance drops to as little as 60 ohms for a length-to-diameter ratio of about 100; in other cases, the reduction is much less for the same ratio. The differences apparently occur as a result of inequalities in the amounts of gap spacing at the center feed point and the type of feed-line connection. Shorter, straight conductors have progressively lower resistances, but they are always accompanied by a capacitive reactance that must be tuned out for best operation. A half-wave folded dipole has an input resistance four times that of a simple dipole, about 292 ohms when the conductors are thin.

c. The radiation resistance varies with the position of the feed point, wherever there is a change in the current amplitude along the length of the conductor. This is always the case with resonant antennas (such as dipoles) that have a standing wave and hence nonuniform distribution of current.

d. The ordinary loop antenna has a radiation resistance of less than 1 ohm, and an inductive reactance is always present. For efficient operation, a variable capacitor is placed across the input to permit tuning to resonance. The loop current is then large but fairly constant over the loop length.

9. ANTENNA GAIN.

a. Generally, the direction of maximum radiation from any antenna is the direction of principal interest in radio communication. The power propagated in that direction is a measure of the beaming power of the antenna. The antenna is rated by a comparison of its radiation along this line with that of a basic or reference antenna of equal total radiated power. The ratio of these two values, expressed as the square of the field intensities at a given point, is called the directivity gain of the antenna.

b. The reference antenna may be a short conductor, or it may be a theoretical point source, called an isotropic radiator, which is assumed to radiate uniformly in all directions and, therefore, has a spherical radiation pattern. The isotropic radiator has a gain of unity, and all other antennas have a greater gain, since the slightest deviation in the spherical pattern signifies an increase of the field in some direction over that for the uniform field. This is always compensated for by a smaller field in some other direction, since the total radiated power is assumed to be constant.

c. In more complicated antenna arrangements, it is common practice to use the half-wave dipole as a reference element. The gain of an antenna in terms of a half-wave dipole, or in terms of a short conductor, can be converted to the isotropic reference by adding the gain of either of these (in dB) with respect to the isotropic radiator. The respective values are shown in the following chart.

	Gain versus isotropic radiator: Numerical ratio (power)	dBi
Short conductor	1.50	1.76
Half-wave radiator	1.64	2.15

d. A half-wave dipole radiating a power of 1kW in free space develops a field intensity of 137.6 millivolts per meter at 1 mile (1.6km) in the direction of maximum radiation.

e. When an antenna has appreciable loss in its tuning elements or in the ground connection, the power radiated may be only a fraction of that delivered by the transmitter.

10. ANTENNA BANDWIDTH.

a. A resonant antenna, such as a half-wave dipole, is generally adjusted in length so as to be tuned to a specific frequency. It therefore has a certain input resistance at this frequency. At frequencies increasingly displaced from this reference frequency, the resistance changes somewhat and reactance is introduced. Both of these changes affect the impedance match to the connected apparatus. The band of frequencies over which these deviations remain within specified limits is called the bandwidth of the antenna. In general, antennas made of thick conductors (or several thin conductors in multiple and usually fanned out) have smaller impedance variations for a given frequency displacement from midband and, therefore, have wider band characteristics than thin-conductor antennas.

b. With most practical antennas, the impedance match is not greatly changed over a frequency band equal to a few percent of the carrier frequency. Most resonant-type antennas, therefore, inherently have sufficient bandwidth to accommodate the sidebands introduced by modulation of the carrier by the signal. For voice or data transmission in the hf band and higher, the average dipole antenna has sufficient bandwidth to handle several multiplexed channels without noticeable discrimination. Multiple arrays tend to narrow the bandwidth appreciably relative to a single element.

c. For reliable skywave transmission in the hf range, it is usually necessary to change frequencies two or more times over a 24-hour period. This requires greater bandwidth than can be included in a resonant-type antenna, so that when half-wave horizontal dipoles are used it is necessary to change antennas with a shift in frequency. The other alternative is to use a nonresonant-type radiator, such as a rhombic antenna, which has an inherently wider band characteristic and can accommodate a 2- or 3-to-1 change in frequency with relatively moderate impedance changes and minor changes in current distribution.

11. RECIPROCITY.

a. An antenna may be used to transmit or to receive. The characteristics of radiation pattern, gain, and radiation resistance apply equally well whether the antenna is used for one purpose or the other. As a consequence, a receiving antenna can be beamed to be responsive to an incident field over only a small angle, just as a transmitting antenna is made to radiate a field over only a small angle. In this way, the receiving antenna absorbs more power from the passing wave than if it were not beamed, a fact that is reflected, as in a transmitting antenna, in a higher directivity gain.

b. Over skywave transmission paths, the radio waves may not take the same path through the ionosphere in both directions of transmission. Therefore, the above rule may not always apply. An incoming wave at the receiver may not strike the antenna at the angle, in either the horizontal or vertical plane, that gives the best results. Therefore, different parts of the directive pattern may be used by the incoming waves and some departure from complete reciprocity results. But this situation is rare. Any observed departure from reciprocity is more likely to be caused by differences in equipment or noise level at the two locations.

12. POWER ABSORBED BY RECEIVING ANTENNAS.

a. A passing wave induces a current in a conductor placed in the proper plane of polarization. By breaking the conductor somewhere along its length and placing a load resistance in it (or connecting directly to widely separated points on an unbroken conductor), a localized voltage is produced. This voltage can be amplified in a receiver bridged across the conductor. As in the transmitting case, the break for a half-wave dipole is usually made at the center in a quarter-wave whip or mast. The break is usually at the ground end. In either case, a transmission line is run from the break to the receiver, where the resistance may take the form of an actual resistance unit. Or it may be a transformer network that steps up the impedance to that of a first rf stage. Where a shunt connection is made to widely separated points of unbroken conductor, a tapered line is necessary for impedance matching, as exemplified by the delta-match antenna.

b. When a receiver has the same input resistance as is seen across the antenna connection, it is said to be matched to the antenna. In such a case, one-half of the induced voltage appears across the receiver, the other half across the internal (radiation) resistance of the antenna. The wave at the receiver can be assumed to be a plane wave. If the antenna is in line with the direction of polarization of the field, the total, induced voltage is the product of the field strength (μV/m) and the effective length. The actual length of a resonant-type antenna cannot be used in this product because the current is not uniform, but has a standing-wave distribution. The effective length is the length the antenna would have if the current were uniform and the antenna absorbed the same amount of power. In the case of a half-wave dipole and a quarter-wave whip, it is 0.636 times the actual length. For shorter lengths of dipoles and whips, the effective length approaches one-half the actual length. The absorbed power is then the square of the voltage across the receiver input divided by its ac resistance. For example, suppose that a half-wave dipole with a physical length of 1.5 meters is placed in a 100MHz field that has an intensity of 10μV/m parallel to the antenna, then the induced voltage is the product of this field intensity and the effective length, or $10 \times (1.5 \times 0.636)$, which equals 9.54$\mu$V. The voltage across the matched receiver (assume a 73-ohm match) is one-half of 9.54μV, or 4.77μV; and the absorbed power is $(4.77)^2 \div 73 = 0.312$ picowatt (pW). With other receiving antennas, the gain (in dB) relative to a half-wave dipole is added to obtain the absorbed power.

c. When using tuning units having internal losses, when grounding systems of appreciable resistance are present, or when an antenna is operated off its resonant frequency, it is necessary to consider such conditions in determining the net absorbed power. They introduce additional losses that reduce the efficiency of the receiving system. This reduction in efficiency is not detrimental when external noise controls the received signal-to-noise ratio, since signal and noise are then reduced together. In transmitting antennas, or in receiving antennas when equipment noise is controlling, it is always desirable that losses be reduced to a minimum.

APPENDIX 7. ORIENTATION OF HIGH-FREQUENCY (HF) DIRECTIVE ANTENNAS

1. GENERAL.

a. Because a high-frequency (hf) antenna for point-to-point (ptp) operation is highly directive, it naturally must be pointed exactly in the proper direction. Radio waves in the hf bands follow a great-circle route as they are reflected by the ionosphere. Therefore, it is necessary to calculate the transmitting azimuth of the great-circle route to the receiving station. The same is true for the reverse path: the distant station must point its transmitting antenna at the correct great-circle azimuth to the distant (local) receiving station. Figure 2-40, in chapter 2, illustrates the three great-circle models from which calculation are made: part A, when both receiving and transmitting stations are north of the equator; part C, when both receiving and transmitting stations are south of the equator; and part B, when the great-circle path spans the equator. Azimuth and distance calculations described in this appendix will assist the reorienting of existing antennas if there is a need to relocate circuits or relocate transmitter or receiver stations. They are useful to initially orient or reorient rotatable log-periodic, quad, or yagi hf directional antennas such as may be used in the interregional emergency network or ship-to-shore circuits. Great-circle charts centered on large cities throughout the world are published and may be used for rough determinations of great-circle azimuth.

b. The calculations involve the use of natural trigonometric functions. These functions may be obtained from published tables or, most conveniently, directly from any one of several "slide-rule" electronic calculators. The latter instrument considerably eases the labor and improves the accuracy of great-circle calculations.

c. The stations marked A and B in figure 2-40 correspond to the notation A and B in the formulas given in the procedure below.

2. PRELIMINARY PROCEDURE.

To assist in obtaining a concept of the great-circle arc to stretch between the transmitting and receiving points on the earth, a moderate-sized library globe may be used initially to lay out the path. From this, a rough determination of latitude, longitude, and azimuth can be obtained. More precise latitude and longitude in degrees and minutes are required for actual great-circle calculations. For these, a large-scale map or charts of Mercator projection showing the individual transmitting and receiving sites are suitable. If necessary, the data can be obtained through survey procedures. In preparing for the calculations, it is useful to ascertain the mathematical signs (+ or −) to be used with the various functions in paragraph 3.

Both Points in East Longitude	*Both Points in West Longitude*	*One Point in East Longitude; One Point in West Longitude*
If longitude of A is greater than longitude of B, A is east of B; if less, A is west of B.	If longitude of A is greater than longitude of B, A is west of B; if less, A is east of B.	If A is in east longitude, A is east of B unless arithmetic sum of the longitudes is greater than 180°. Then A is west of B. If A is west longitude, A is west of B unless arithmetic sum of the longitudes is greater than 180°.

3. BASIC FORMULAS AND SYMBOLS FOR CALCULATIONS.

a. There are three basic formulas for determining great-circle data. They are:

(1)

$$\text{Cos}\, D_{a-b} = \text{Sin}\, L_a \,\text{Sin}\, L_b + \text{Cos}\, L_a \,\text{Cos}\, L_b \times \text{Cos}\, L_o$$

(2) $$\text{Sin}\, C_a = \frac{\text{Cos}\, L_b \,\text{Sin}\, L_o}{\text{Sin}\, D_{a-b}}$$

(3) $$\text{Sin}\, C_b = \frac{\text{Cos}\, L_b \,\text{Sin}\, L_o}{\text{Sin}\, D_{a-b}}$$

b. Formula (1) computes the great-circle distance from A to B in minutes of arc or nautical miles (1 minute of arc = 1 nautical mile = 1.853km = 1.152 statute miles).

c. Formula (2) computes the azimuthal direction of B from A, in degrees east or west from north in the northern hemisphere and from south in the southern hemisphere.

d. Formula (3) computes the azimuthal direction of A from B.

e. Explanation of symbols.

(1) L_a = latitude of station A, positive for north latitude, negative for south latitude.

(2) L_b = latitude of station B, positive for north latitude, negative for south latitude.

(3) L_o = difference in longitude between A and B.

(4) C_a = direction of B from A (great circle).

(5) C_b = direction of A from B (great circle).

4. SURVEYING THE ANTENNA.

The following steps apply to a rhombic antenna. The end poles are aligned along the azimuthal axis of the array. The azimuthal angles are C_a and C_b calculated in paragraph 3. The angle used depends on whether the local station is at point A or at point B. Refer to the plan view illustration of the rhombic antenna, figure 1, for construction elements of the antenna.

a. Place a transit at the design center of the antenna, with plumb line over the center stake. Adjust the transit for 0° elevation angle on the vertical circle.

b. Adjust the horizontal circle and vernier for 0° at true north.

c. Swing the transit horizontally from 0° to the C_a or C_b azimuth on the horizontal circle.

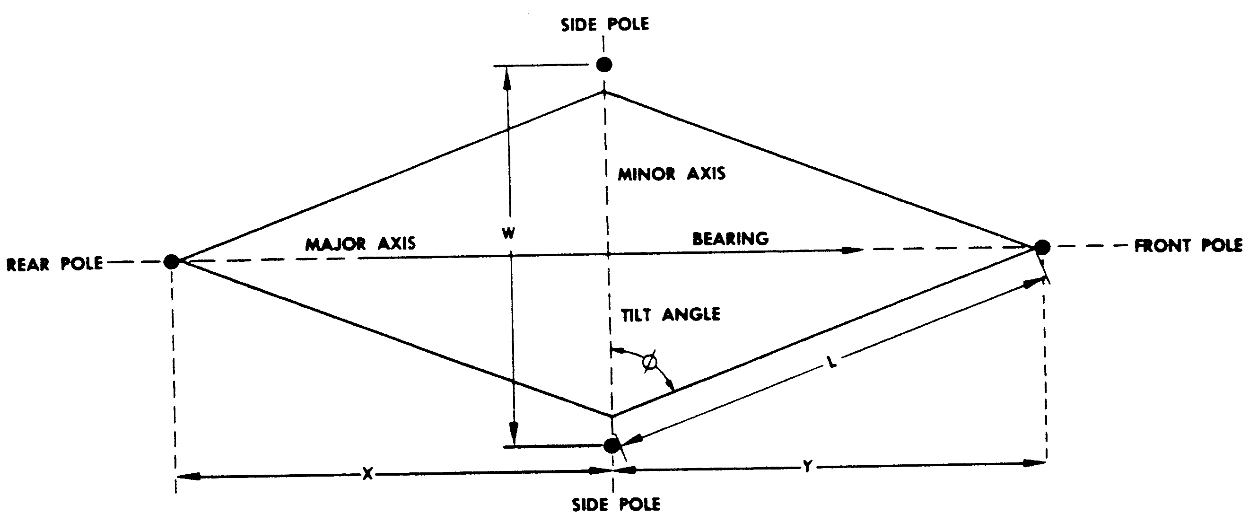


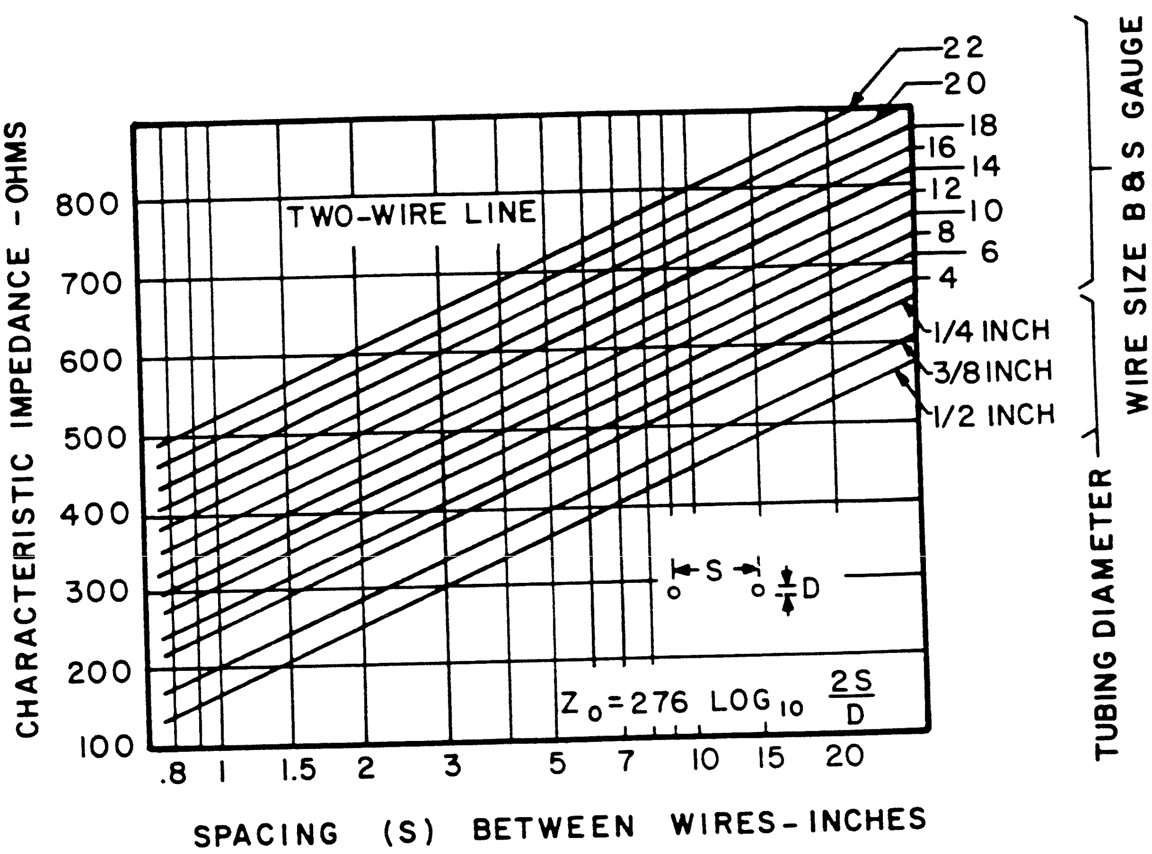
Figure 1. Plan View of Rhombic Antenna

d. Stake out the location for the end pole to support the radiating apex of the antenna, at the correct distance from the center stake of the array (one-half the total design length of the antenna).

e. Rotate the transit exactly 180°. This sights the back azimuth of the array. Stake out the end pole location at the driven end of the axis at the same distance used for the radiating end pole.

f. Horizontally rotate the transit + or − 90°. Stake out one side pole location at the distance required by the antenna design.

g. Horizontally rotate the transit 180°. Stake out the other side pole location at the same distance of step f. This completes staking the two end poles and the two side poles. Pole locations for a dissipation line (at the radiating end of the axis) and feed line (at antenna back azimuth) can be staked out from engineering drawings that show the other construction details of the particular rhombic. The stake at the radiating end of the antenna should be painted red or otherwise clearly marked to prevent the wrong stake from being used during later phases of construction.



NOTE:

WIRE SIZE (B & S)	4	6	8	10	12	14	16	18	20	22
WIRE DIAM (MILS)	204	162	128	102	81	64	51	40	32	25

Figure 2. Two-Wire Line Characteristics

*U.S. GOVERNMENT PRINTING OFFICE:1992-668-016/61037

(7) **Length L of a Vertical Dipole Antenna.**

$$L_{inches} = \frac{5600}{\text{Frequency in MHz}}$$

b. Transmission Line Formulas.

(1) **Impedance of Two-Wire, Open-Wire Line.**

$$Z_o = 276 \log_{10} \frac{2S}{D}$$

where D = diameter of the wire and

S = center-to-center spacing between conductors

NOTE: See figure 2 of this appendix for a plot of this formula.

(2) **Impedance of Coaxial Cable.**

(a) Air-Insulated.

$$Z_o = 138 \log_{10} \frac{D}{d}$$

where D = inside diameter of outer conductor and

d = outside diameter of inner conductor (same units as D)

(b) Solid-Dielectric.

$$Z_o = \frac{138}{\sqrt{\epsilon}} \log_{10} \frac{D}{d}$$

where ϵ = dielectric constant of the insulating material (e.g., ϵ = 2.25 for polyethylene)

c. Standing-Wave Ratio (SWR) Formulas.

(1) **Using Trolley Meter on Open-Wire Line.**

$$SWR = \sqrt{\frac{\text{maximum meter deflection}}{\text{minimum meter deflection}}}$$

(2) **Using the Directional Wattmeter.**

* $$SWR = \frac{1 + \sqrt{\frac{\text{Reflected Power}}{\text{Forward Power}}}}{1 - \sqrt{\frac{\text{Reflected Power}}{\text{Forward Power}}}}$$ *

NOTE: See figure 3 of this appendix for a plot of this formula.

(3) **Reflection Coefficient Related to SWR.**

$$k = \frac{SWR - 1}{SWR + 1}$$

(4) **For Resistive Loads.**

$$SWR = \frac{Z_o}{Z_L} \text{ or } \frac{Z_L}{Z_o}$$

Z_L = impedance of load

Z_o = characteristic impedance of the line

NOTE: SWR is ≥ 1.0.

(5) **Expressed in Decibels for Voltage Ratio (VSWR).**

$$SWR_{dB} = 20 \log_{10} VSWR = 20 \log_{10} \frac{V_{max}}{V_{min}}$$

d. Matching Section Formulas.

(1) **Impedance of Open-Wire, Quarter-Wave Section.**

$$Z = \sqrt{Z_1 Z_o}$$

Z_1 = antenna impedance

Z_o = characteristic impedance of connecting line

NOTE: Construction data is located in figures 3, 4, and 5 of this appendix.

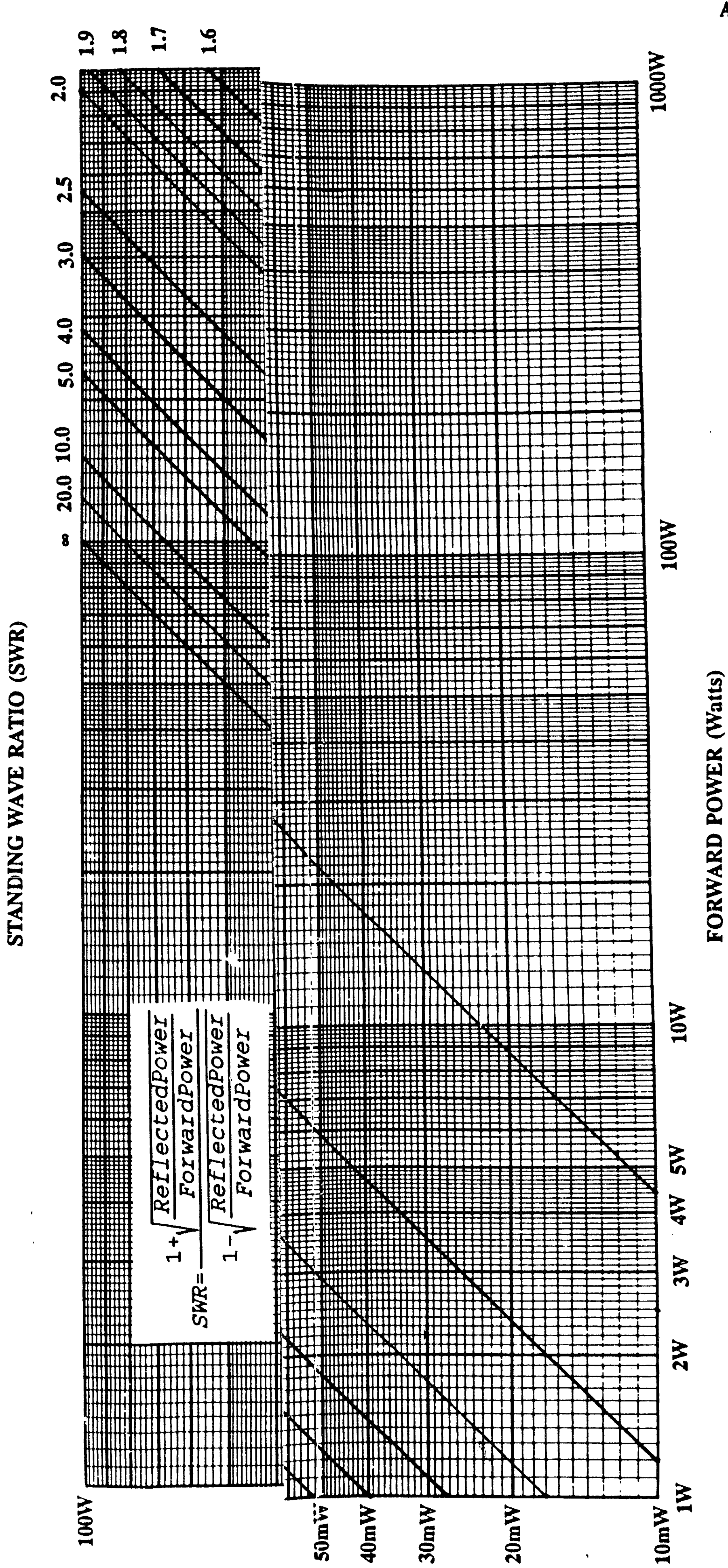


Figure 3. SWR Chart of Forward Versus Reflected Power

(2) **Length L of Open-Wire, Quarter-Wave Section.**

$$L_{feet} = \frac{246V}{\text{Frequency in MHz}}$$

where V = velocity factor

(3) **Delta-Match of Feeder to a Half-Wave Dipole.**

$$L_{feet} = \frac{468}{\text{Frequency in MHz}}$$

where L = length of the half-wave dipole to be matched

$$E_{feet} = \frac{148}{\text{Frequency in MHz}}$$

where E = clearance between the dipole and the beginning of 600-ohm tranmission line

$$C_{feet} = \frac{118}{\text{Frequency in MHz}}$$

where C = spread of feeder at point of attachment to the dipole

NOTE: For the above formulas, the frequency in MHz will be the same value for a given delta-match construction.

e. Propagation Formulas.

(1) **Free-Space Field Intensity.**

$$E_o = \sqrt{\frac{30GP}{D}}$$

E_o = free-space field strength in volts per meter

D = distance in meters

P = radiated power in watts

G = power gain ratio of transmit in antenna

(2) **Free-Space Loss, Between Half-Wave Dipole Antennas:**

$$L_f = 32.3 + 20 \log_{10} f + 20 \log_{10} D$$

where L_f = free-space propagation loss in dB

f = frequency in MHz

D = distance between antennas in nautical miles

(3) **Free-Space Loss Between Isotropic Antennas.**

$$L_f = 38 + 20 \log_{10} f + 20 \log_{10} D$$

(See par 94 for usage)

(4) **Transmission Over Obstructions.**

$$H_{feet} = H_o - \left[\frac{H_B d_1 + H_A d_2}{D} - \frac{d_1 d_2}{1.5K} \right]$$

where H_A = height of antenna above mean sea level (msl),

H_B = height of aircraft above msl,

H_o = height of obstruction above msl,

d_1 = distance of obstruction from antenna in statute miles,

D = distance of aircraft from antenna in statute miles,

d2 = D − d1 in statue miles,

K = equivalent earth's radius factor (nominally 1.33 for frequencies above 100MHz)

3. CHARTS AND NOMOGRAPHS.

a. Figures 1 through 15 are charts and nomographs useful for evaluating antenna performance and constructing emergency antennas and lines.

b. Table 1 gives technical characteristics of flexible coaxial transmission line (common types used for communication).

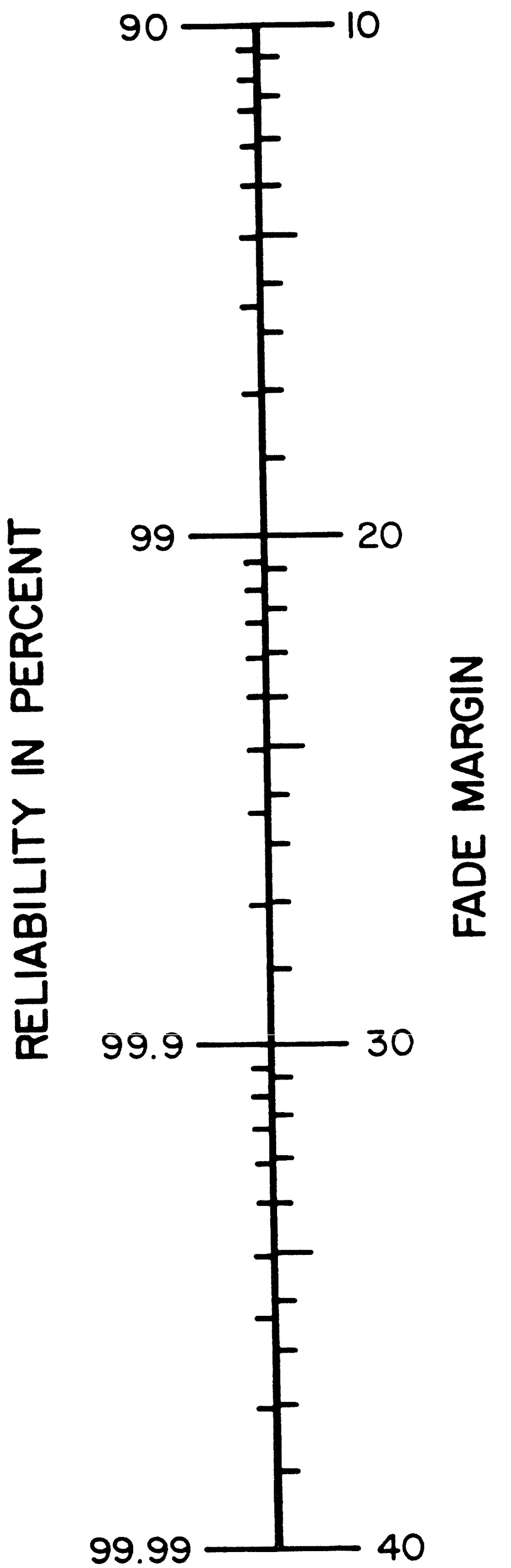


Figure 4. Reliability Nomograph

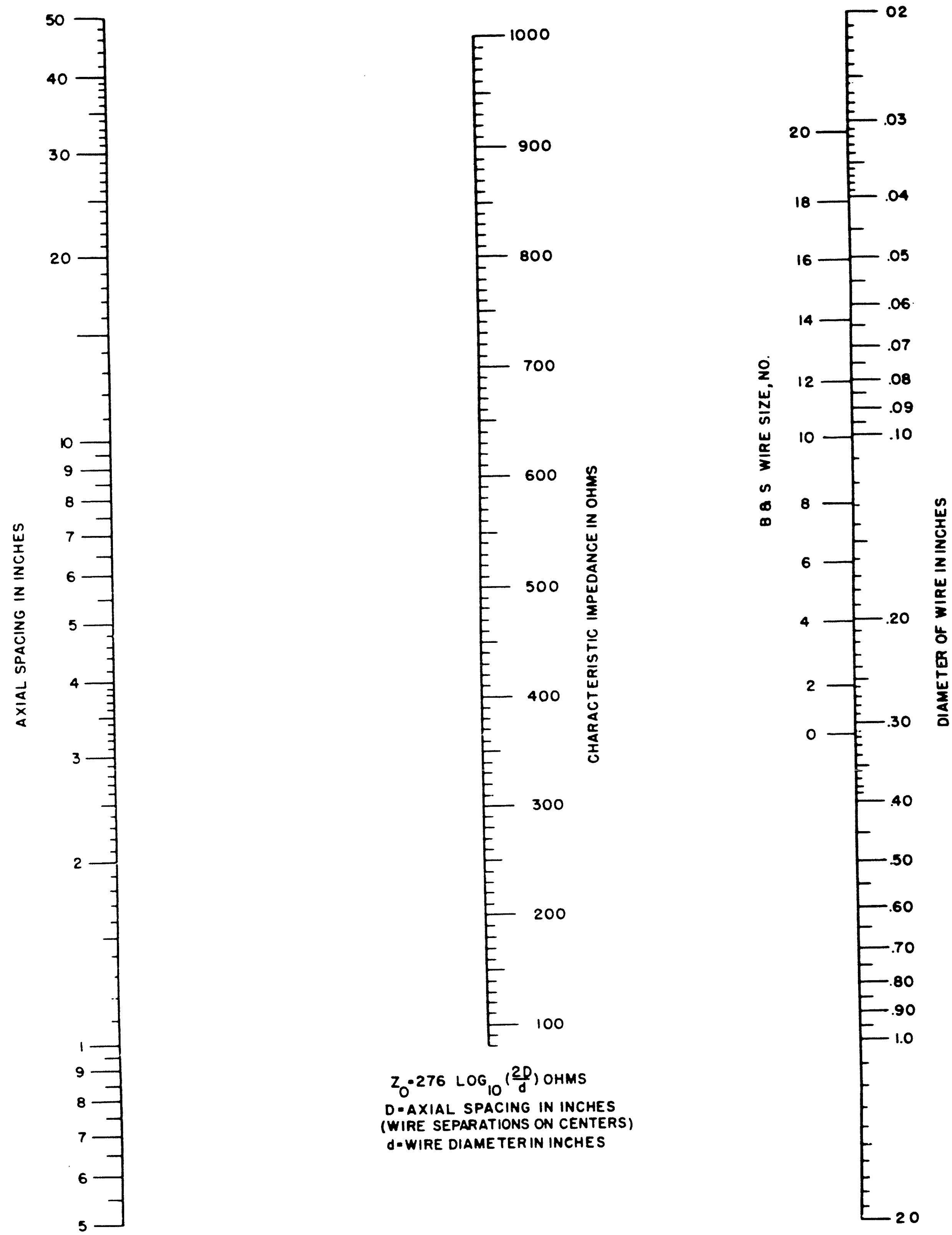


Figure 5. Open-Wire Line Characteristic Impedance

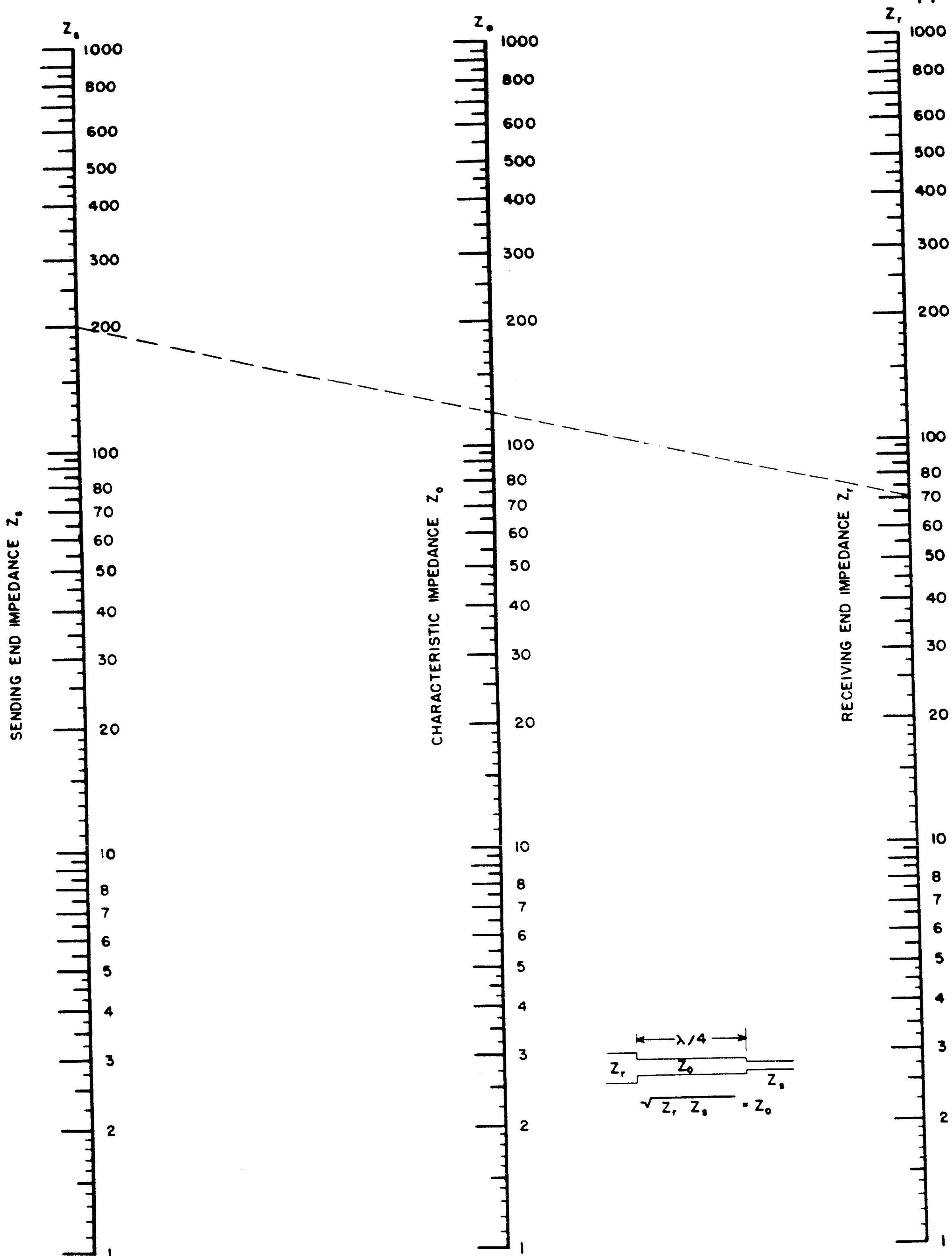


Figure 6. Quarter-Wave Matching Section Characteristic Impedance

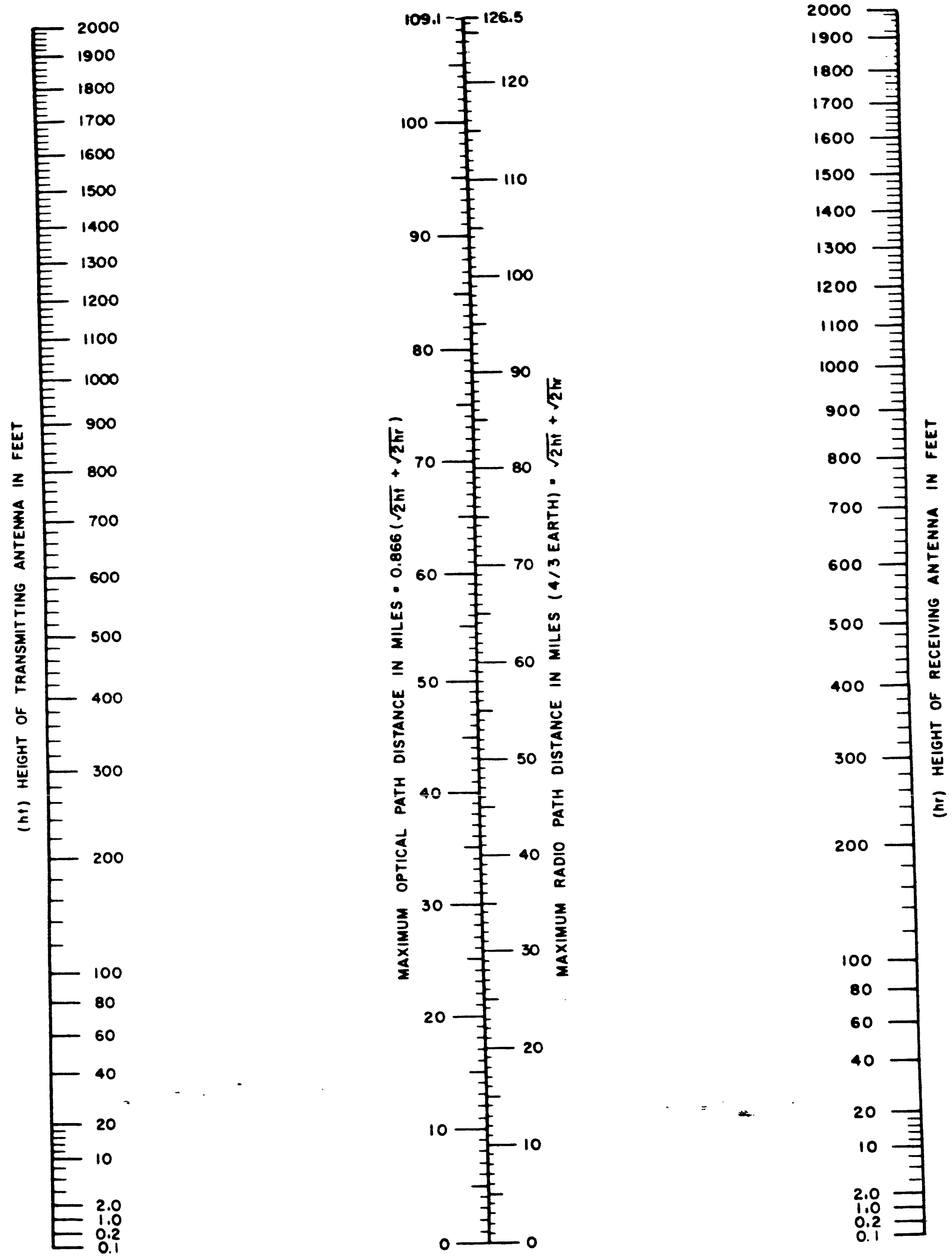


Figure 7. Radio and Optical Line-of-Sight Distances

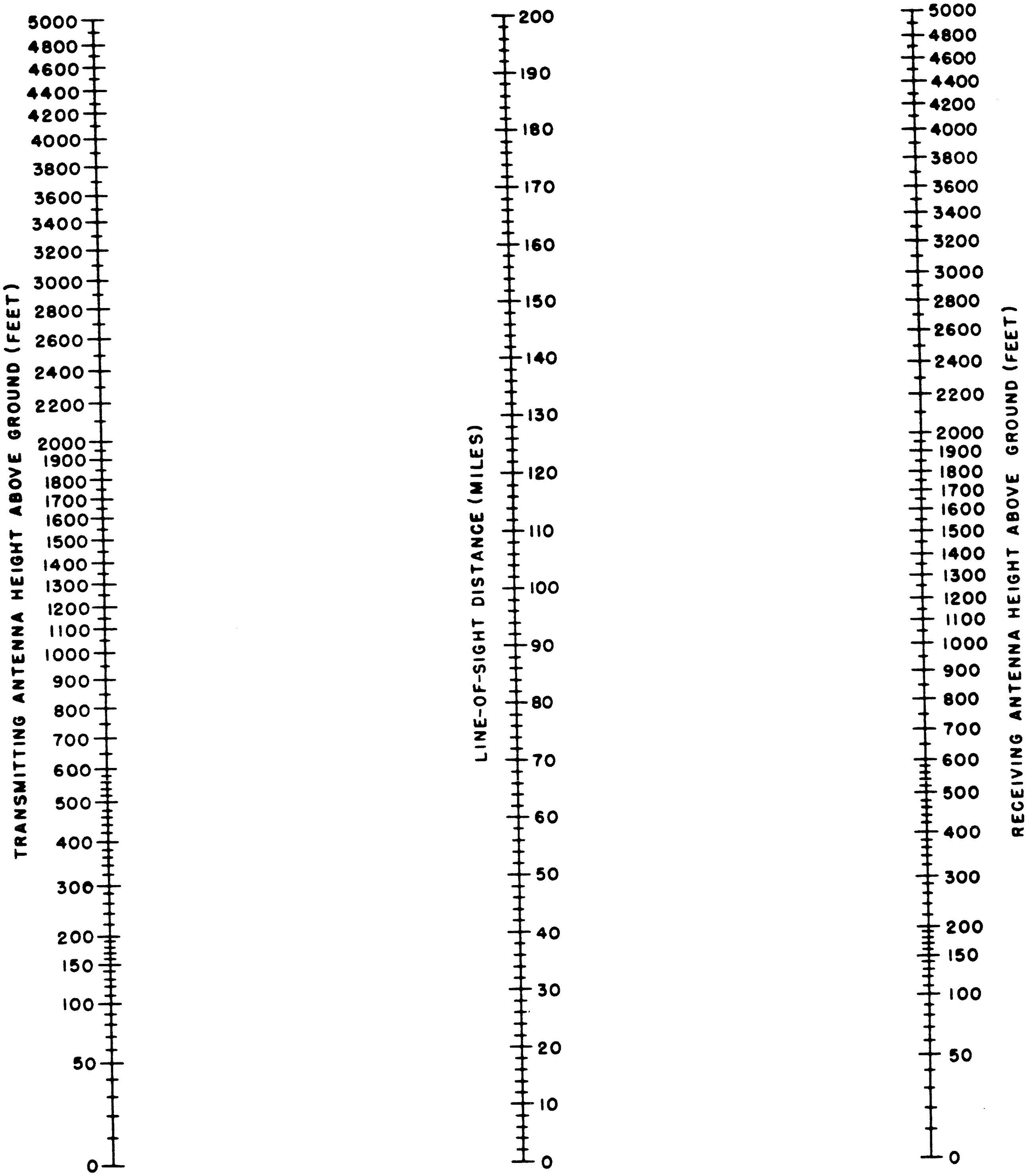


Figure 8. Line-of-Sight Distances for Elevated Antennas to 5,000 Feet

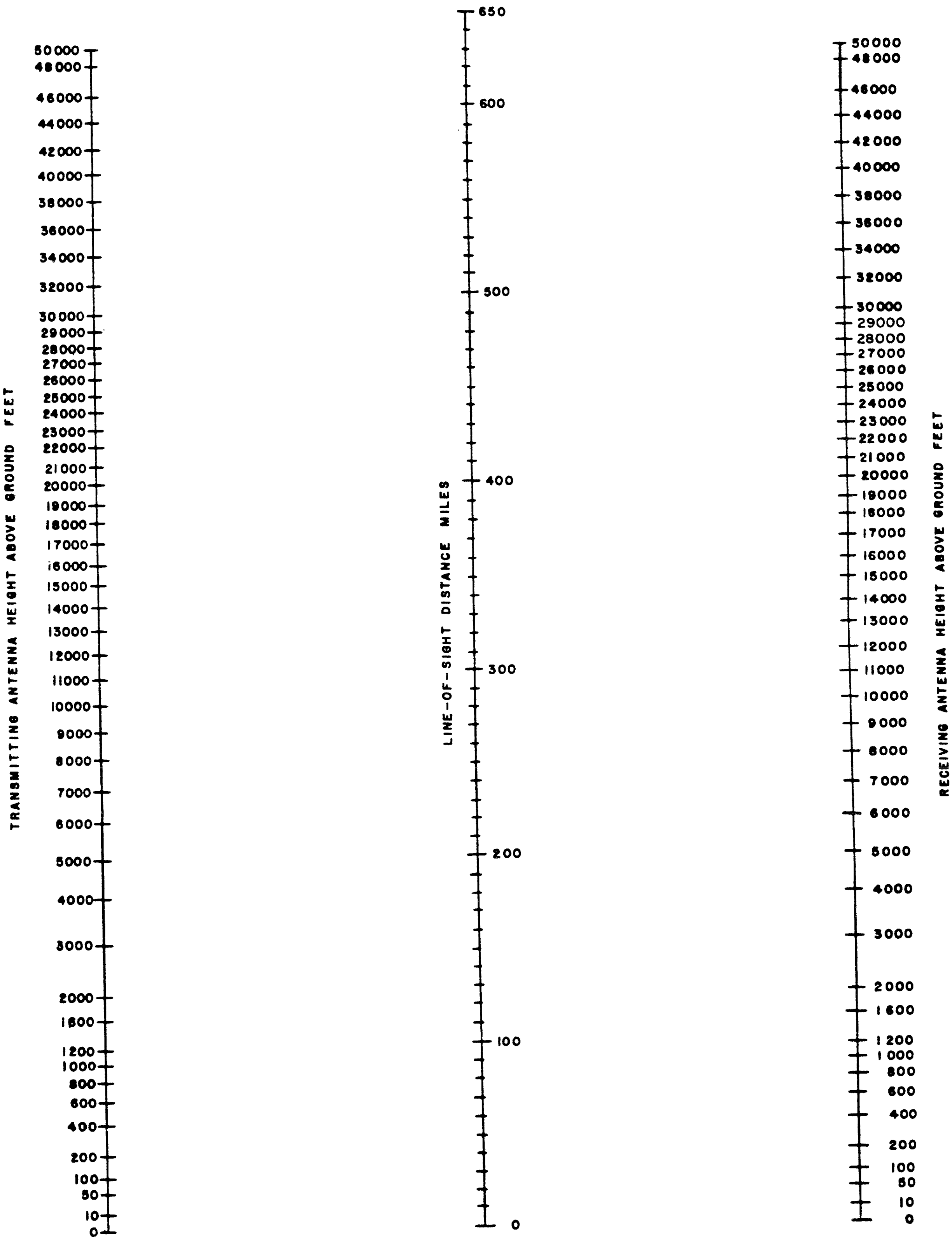


Figure 9. Line-of-Sight Distances for Elevated Antennas to 50,000 Feet

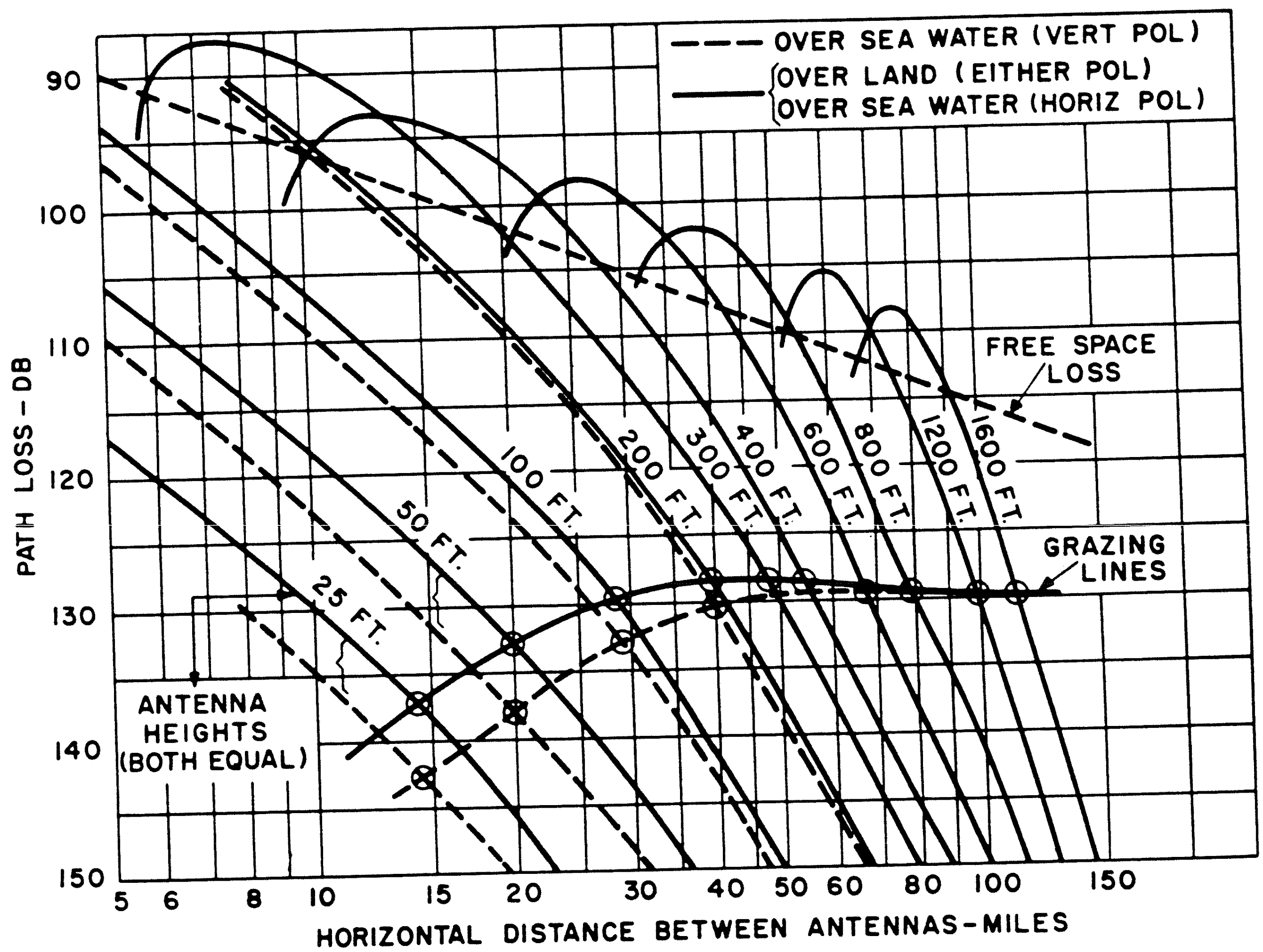


Figure 10. Path Attenuation at 150MHz

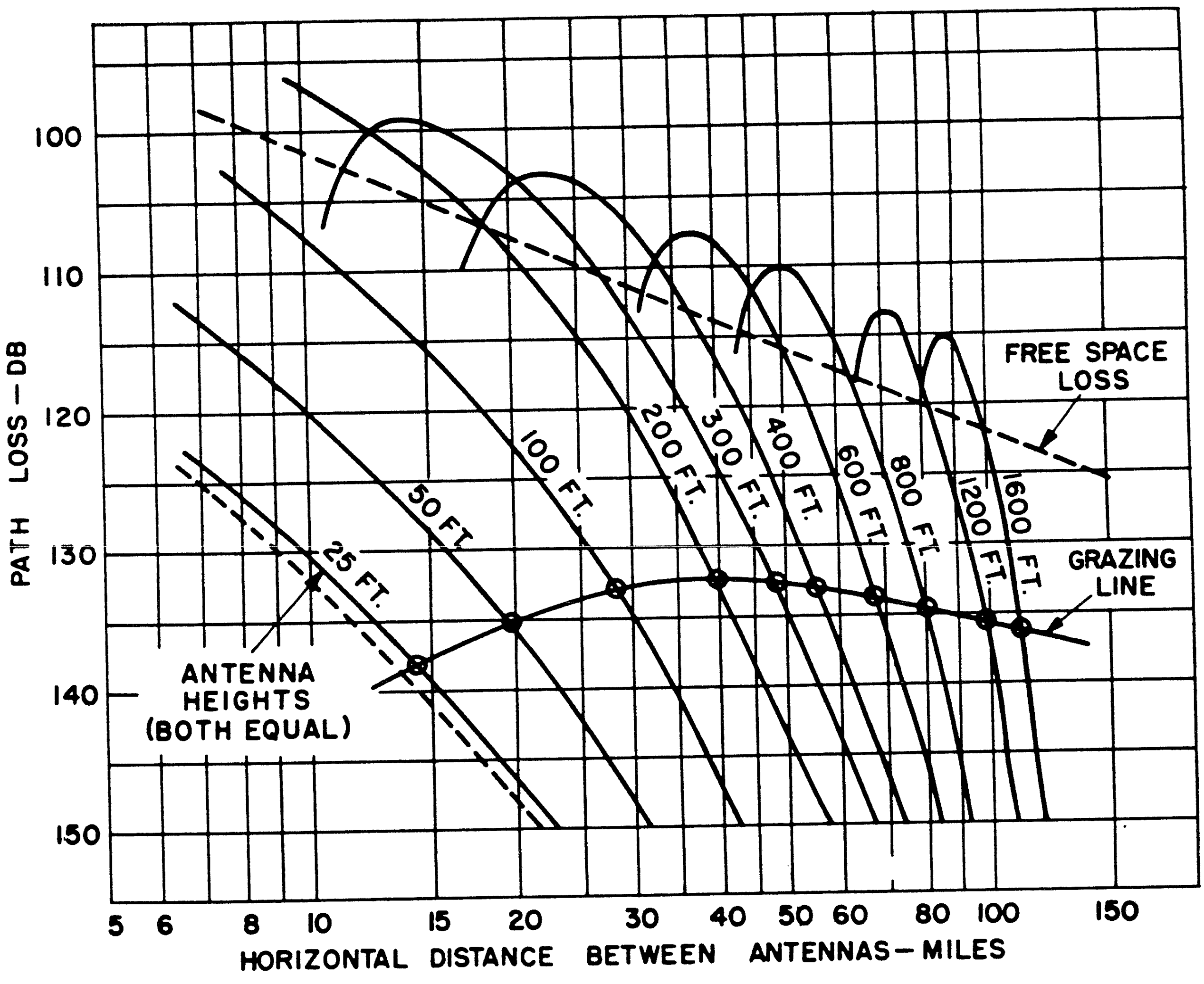


Figure 11. Path Attenuation at 300MHz

$$H = H_o - \left[\frac{H_B d_1 + H_A d_2}{D} - \frac{d_1 d_2}{1.5K} \right]$$

H = IN FEET

H_A = HEIGHT OF ANTENNA AMSL, FEET

H_B = HEIGHT OF AIRCRAFT AMSL, FEET

H_o = HEIGHT OF OBSTRUCTION AMSL FEET

d_1 = DISTANCE OF OBSTRUCTION FROM ANTENNA, STATUTE MILES

D = DISTANCE OF AIRCRAFT FROM ANTENNA, STATUTE MILES

d_2 D-d_1, STATUTE MILES

K = EQUIVALENT EARTH RADIUS FACTOR (USUALLY 1·33)

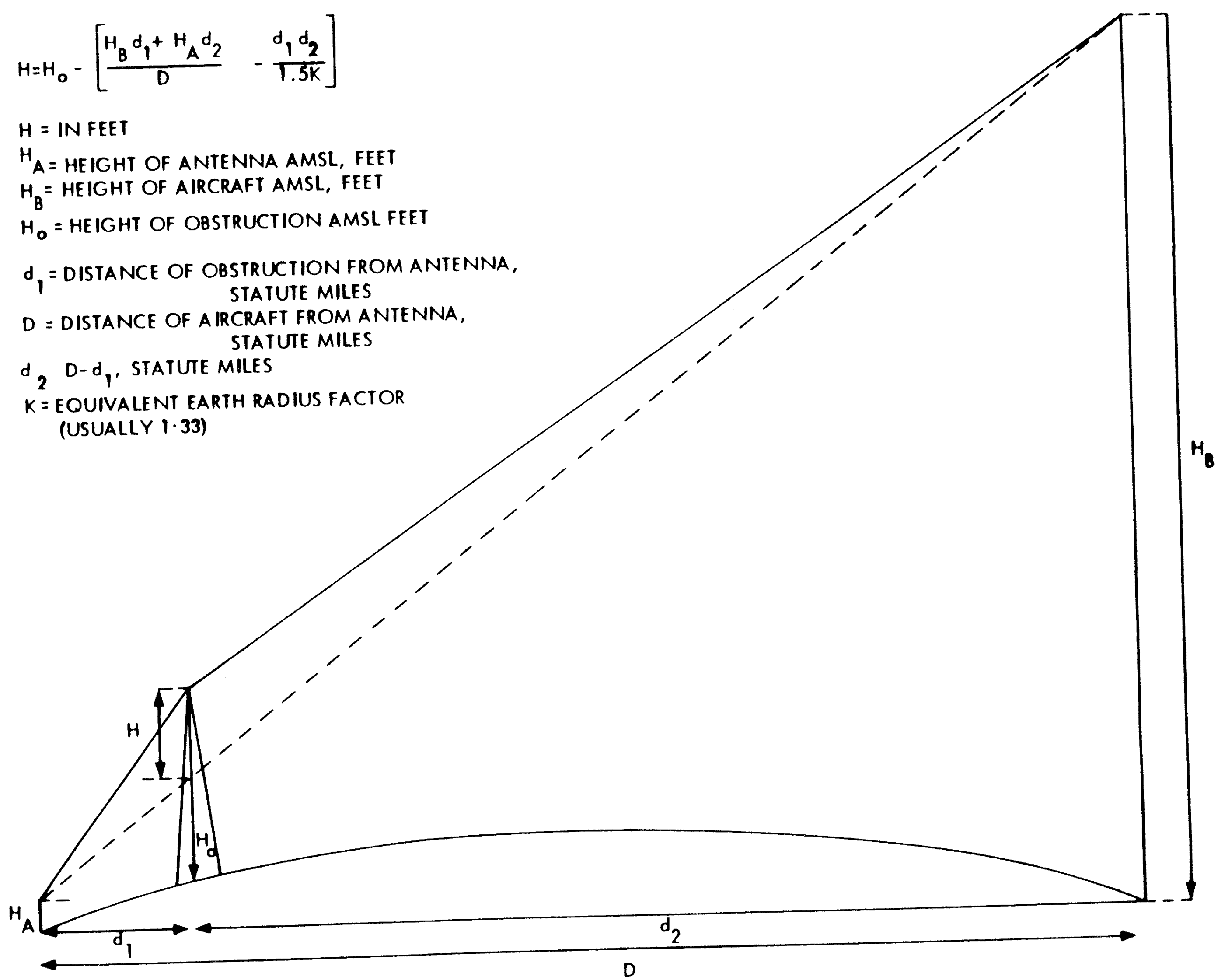


Figure 12. Obstruction Loss Relative to Smooth Earth

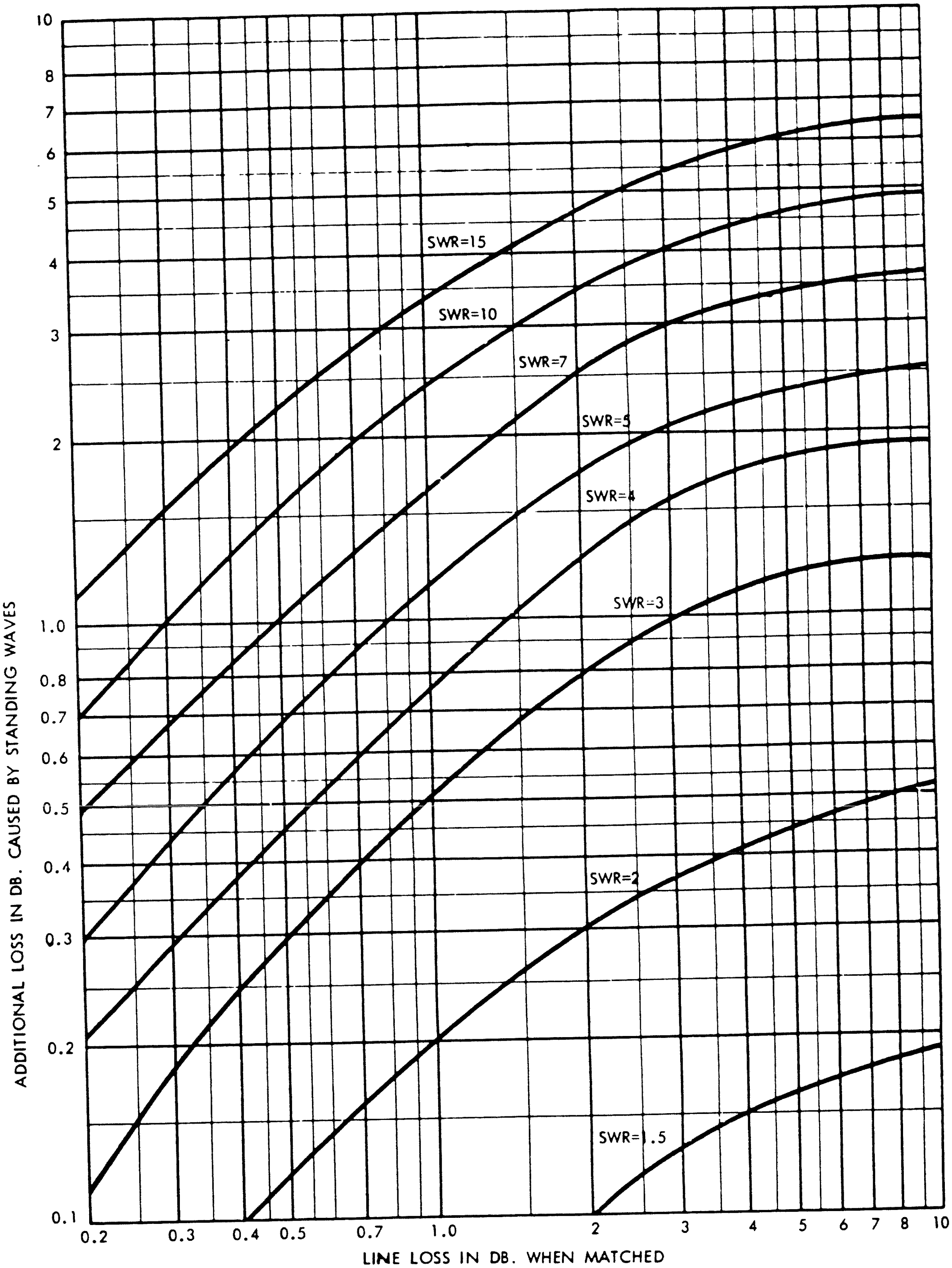


Figure 13. Graph of Additional Losses Caused by Standing Waves

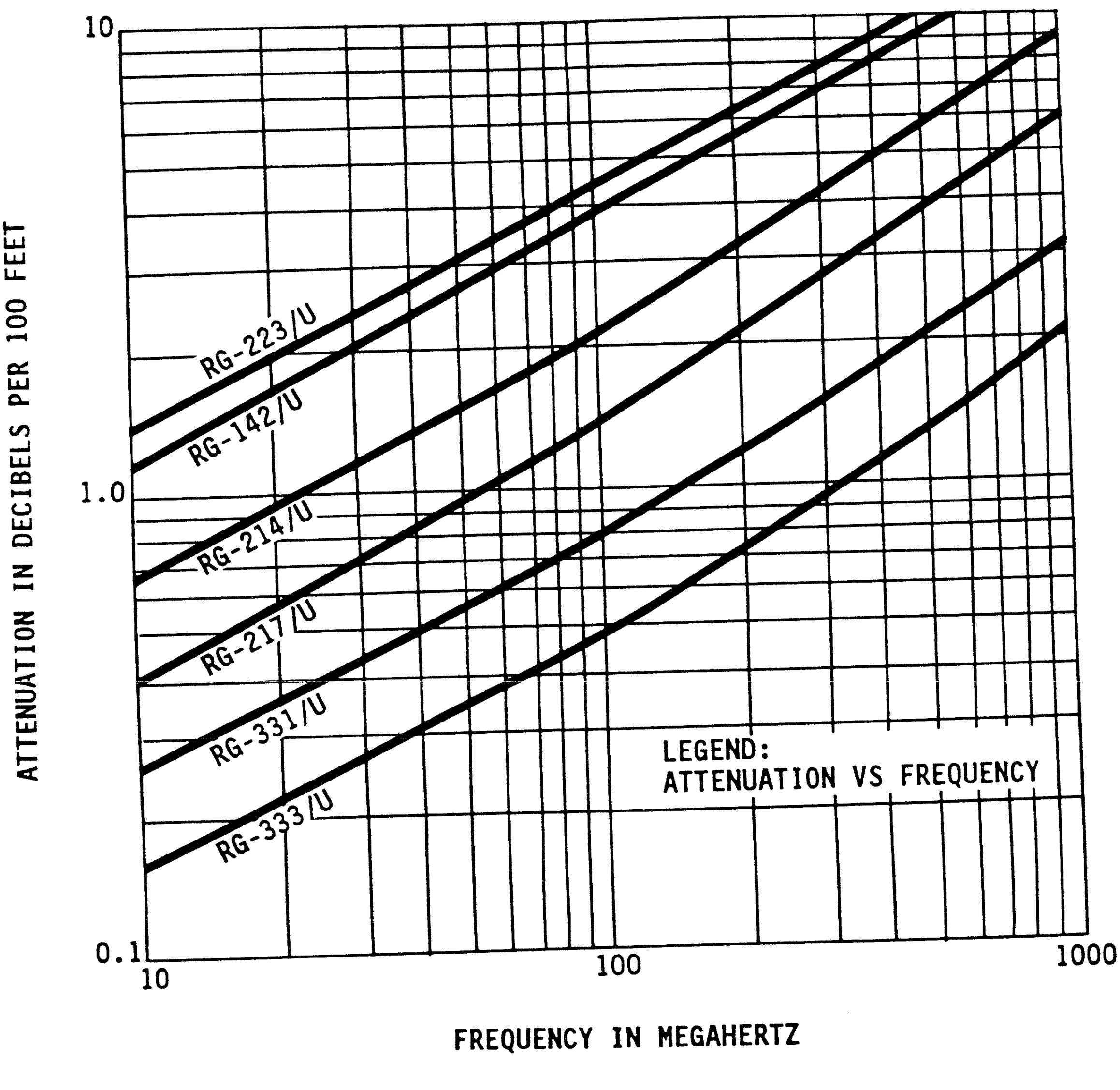
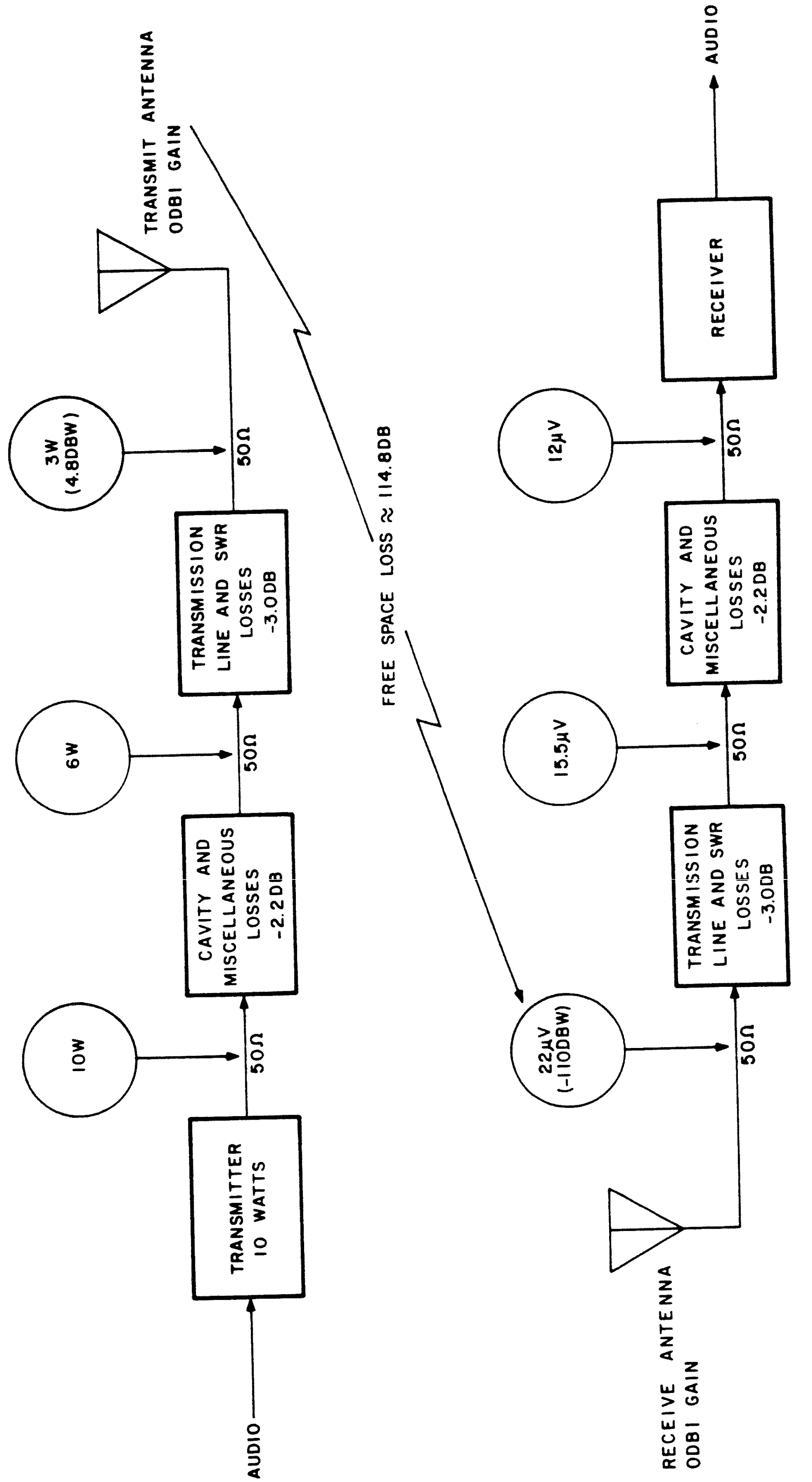


Figure 14. Attenuation Characteristics for Coaxial Cable Types RG-142/U, RG-214/U, RG-217/U, RG223/U, RG-331/U and RG-333/U



NOTES:
1. 12DB MARGIN FOR SYSTEM BASED ON 3.0µV SQUELCH SETTING FOR RECEIVER.
2. UNITY GAIN IS ASSUMED FOR BOTH ANTENNAS.

Figure 15. System Losses in Air-Ground Communication

Table 1. RF CABLE DATA[1]

(Cables Used with VHF and UHF Air-Ground Communication Antennas)

Cable Type RG/U	*Dimensions*					Z_o	*Mil Spec*
	Jacket O.D.-MAX	*Braid[2] O.D.-MAX*	*Dielectric O.D.-MAX*	*Center Conductor*			
				Stranding	*O.D.-NOM*		
142/U	.195	.171D	.116	Solid	.037	50	MIL-C-17/60
214/U	.432	.360D	.292	7/.0296	.089	50	MIL-C-17/75
217/U	.545	.463D	.370	Solid	.106	50	MIL-C-17/78
223/U	.212	.176D	.116	Solid	.035	50	MIL-C-17/84
331/U	.625	.500T	.450	Solid	.162	50	MIL-C-23806/18
333/U	1.052	.875T	.801	Solid	.288	50	MIL-C-23806/28

1 This table is presented as convenient reference only. For detailed specifications, refer to the applicable Mil Spec.

2 D denotes double braid;
T denotes aluminum tube, single covering

APPENDIX 9. FABRICATING EMERGENCY ANTENNAS AND FEED LINES

1. GENERAL.

Severe damage or destruction to a primary antenna and transmission line system requires erecting a substitute system to maintain critical communication. This appendix contains instructions for improvising temporary antennas and their feed lines that operate in the high-frequency (hf) and very-high-frequency (vhf) and/or ultra-high-frequency (uhf) bands. Section 1 concerns supports and guying; section 2 describes emergency antennas, lines, and matching sections.

Section 1. EMERGENCY SUPPORTS AND GUYING

2. SUPPORT POLES.

If the support for the antenna is damaged or destroyed or is unsafe for personnel to climb to repair or replace the antenna, it is necessary to construct a substitute support. The simplest support is a tall tree or pole, such as a telephone pole. If the local telephone company (telco) approves, one of their utility poles near the facility may be used. A tree may be satisfactory; however, radio-frequency (rf) absorption may impair the tree-mounted antenna. Obtaining and raising a pole may be the best substitute procedure. Poles may be obtained from sawmills, utility companies, lumber yards; or they may be found stored along utility rights-of-way and borrowed with permission of the utility. The utility may provide emergency assistance for raising the pole at the site, or it may lend such machinery as earth augers, winch trucks, and ladders. If necessary for agency personnel to erect the pole, the following general instructions should be observed.

a. **Hole Excavation.** The hole excavated for setting the pole must be properly located. Things to consider include the length of run of the transmission line or lines, nearby obstructions, guying requirements, soil characteristics, proximity of electrical powerlines or transformers, and proximity of the permanent antenna tower on which work must be done. The depth of the hole can be obtained from the table for either firm soil or rock; however, rock emplacement should be avoided because an explosive to blast a hole is dangerous to the facility and to personnel. Figure 1, part E, shows a pole using underbracing. This is a mandatory procedure if the ground is swampy or unstable in any other way.

b. **Setting the Pole.** Figure 1 parts A through D show various methods for raising and setting the pole in place. When there is no available machinery, the pole can be raised with pikes as shown in part A of the figure. A gin pole (figure 1 part B) may be used if a block and tackle is available. Utility company equipment such as derricks and power winches make pole-setting easier as shown in parts C and D of the figure. A back-brace may be necessary for the pole to bear against during the raising operation. This can be made of heavy gauge metal, heavy planking, or a short post. Before raising the pole, any hardware such as antenna-mounting bases, guy plates or collars, pole steps, and eyebolts should be installed.

c. **Guying the Pole.** Figures 2 and 3 illustrate various guying methods and attachment and clamping of guy cables. Figure 2 part A shows an improvised plank anchor in a hole. The anchor is fabricated from a ground rod, threaded and with an eye. A log anchor is

Table 1. POLE-SETTING DEPTHS

Length of pole (ft)	*Hole depth in firm ground (ft)*	*Hole depth in rock (ft)*
16 (1.8m)	3½ (1.1m)	3 (0.9m)
20 (6.1m)	4 (1.2m)	3 (0.9m)
25 (7.6m)	5 (1.5m)	3 (0.9m)
35 (10.6m)	6 (1.8m)	4 (1.2m)
50 (15.2m)	7 (2.1m)	4½ (1.4m)
70 (21.2m)	9 (2.7m)	6 (1.8m)
90 (27.3m)	11 (3.3m)	7 (2.1m)

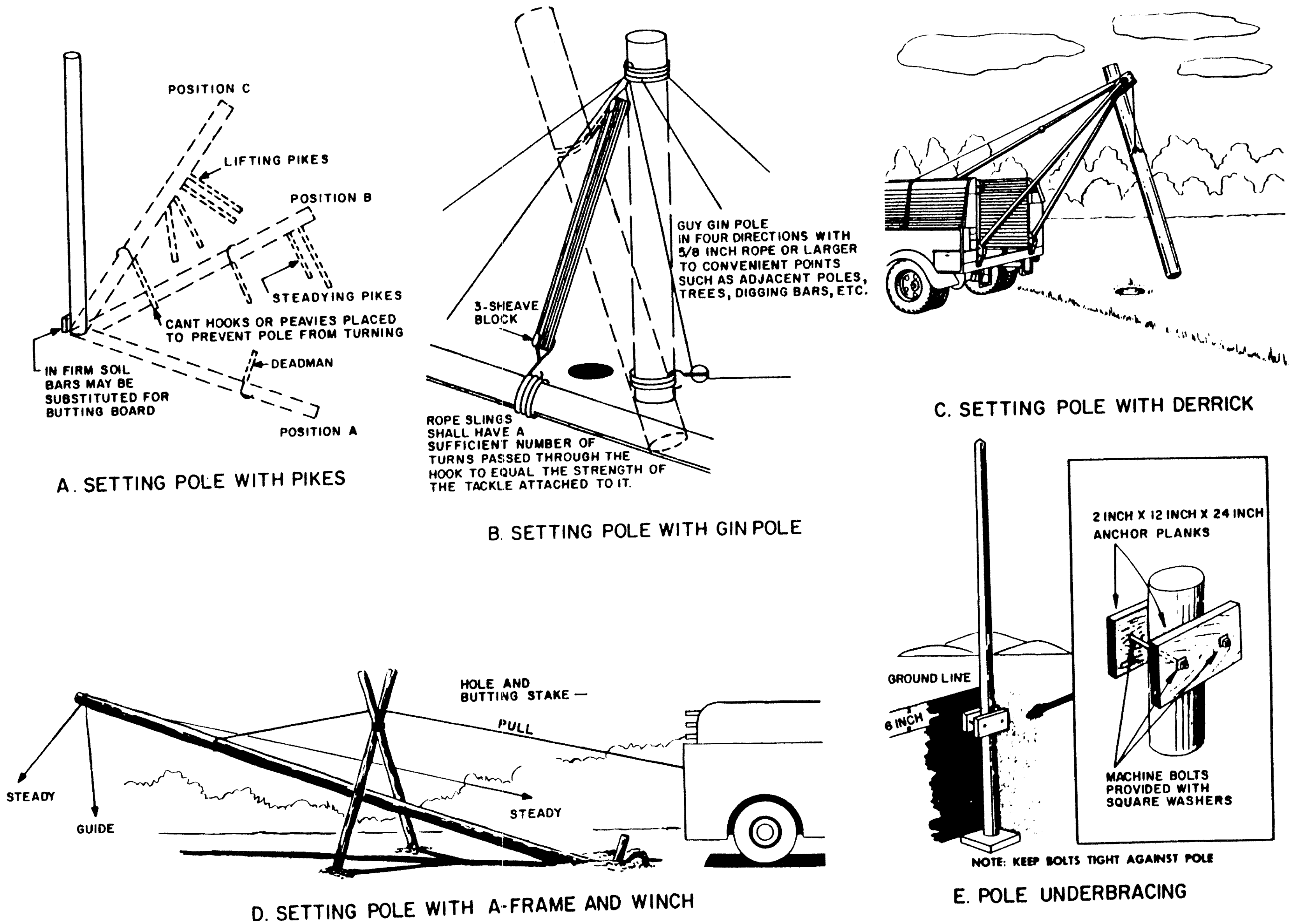


Figure 1. Methods of Raising and Setting Poles

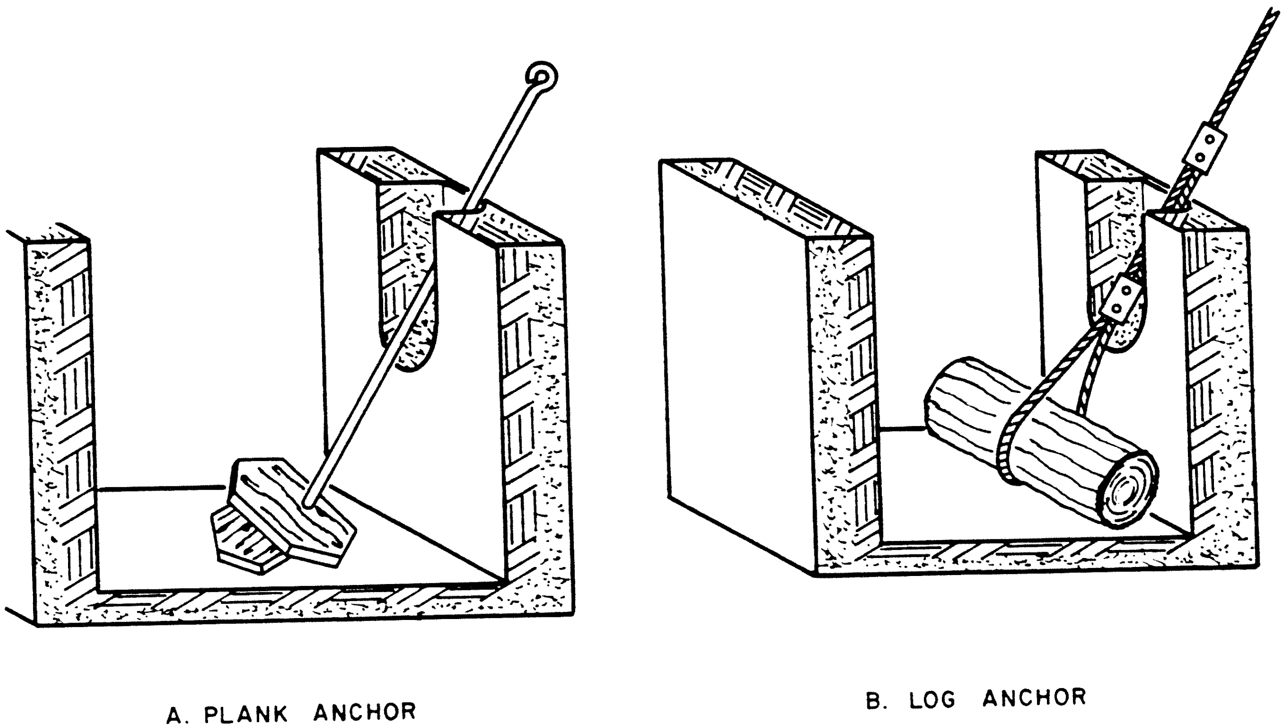


Figure 2. Guy Anchors

shown in part B of the figure. It is simply a short section of tree trunk (a section of heavy timber will also suffice, size 4 by 4 inches and up) around which the guy cable is looped, clamped, and served. Creosote treatment of these anchors may not be necessary in view of their short utilization time. Figure 3 contains four guy tying methods. Part A is the simplest, using an eyebolt through a hole drilled in the pole or stub, held in place with a flat washer and nut. Part B uses a double eyebolt, when back-guying is necessary for additional strength. Part C shows methods of guying and back-guying a bracing stub, which is a short pole set near a larger pole or mast for additional guying strength. Part D illustrates the use of scrap metal to fabricate a guy collar; this method is useful when the pole is relatively large in cross section. It will work for smaller poles, also. Part E of the figure shows the best way to tie a guy to the eye rod of a guy anchor. A clamp is used and the guy cable is served at the end. Serving methods are provided in figure 5. As shown in figure 2, the guy anchors are set in at an angle to provide collinear strain on the guy and cable sections. The angle at which the guy hole is excavated is determined by the distance of the guy anchor from the pole and the height of the guy where it attaches to the hole. This angle can be computed by the tangent formula for a right triangle. Tall poles may have to be guyed at two levels, one at about midway up the pole and the other near the top of the pole. Shorter poles are guyed at about two-thirds their height.

d. Stabilizing the Pole. Four technicians are required to set and guy a pole. A person is needed on each guy while the fourth observes and advises on the vertical aspect of the pole. Guys should be "tensioned" and never made "taut." Shunt dynamometers to measure tension are advisable when large masts or towers are guyed, so that equal tensioning can be applied to each guy cable. For the shorter structures, the "feel" of the guy should be that of some slack and not a violin-string tautness. An inch or so of play should remain after the guy clamps are tightened at the anchor end. During the guy-tightening operation, pikes should be set against the pole at three or more locations around the pole to provide stability during the refinement of guy tension. Loose earth around the base of the pole should be tamped firmly, using tamping rods or sections of 4- by 4-inch or 2- by 4-inch timber. Any depression left after thorough tamping should be filled in with gravel and tamped.

e. Attaching the Antenna. Once the pole is stabilized and can be safely climbed, attach the antenna. If the antenna is a whip, vertical ground plane, or other simple structure such as a coaxial antenna, it is only a matter of attaching it to its base with standard hard-

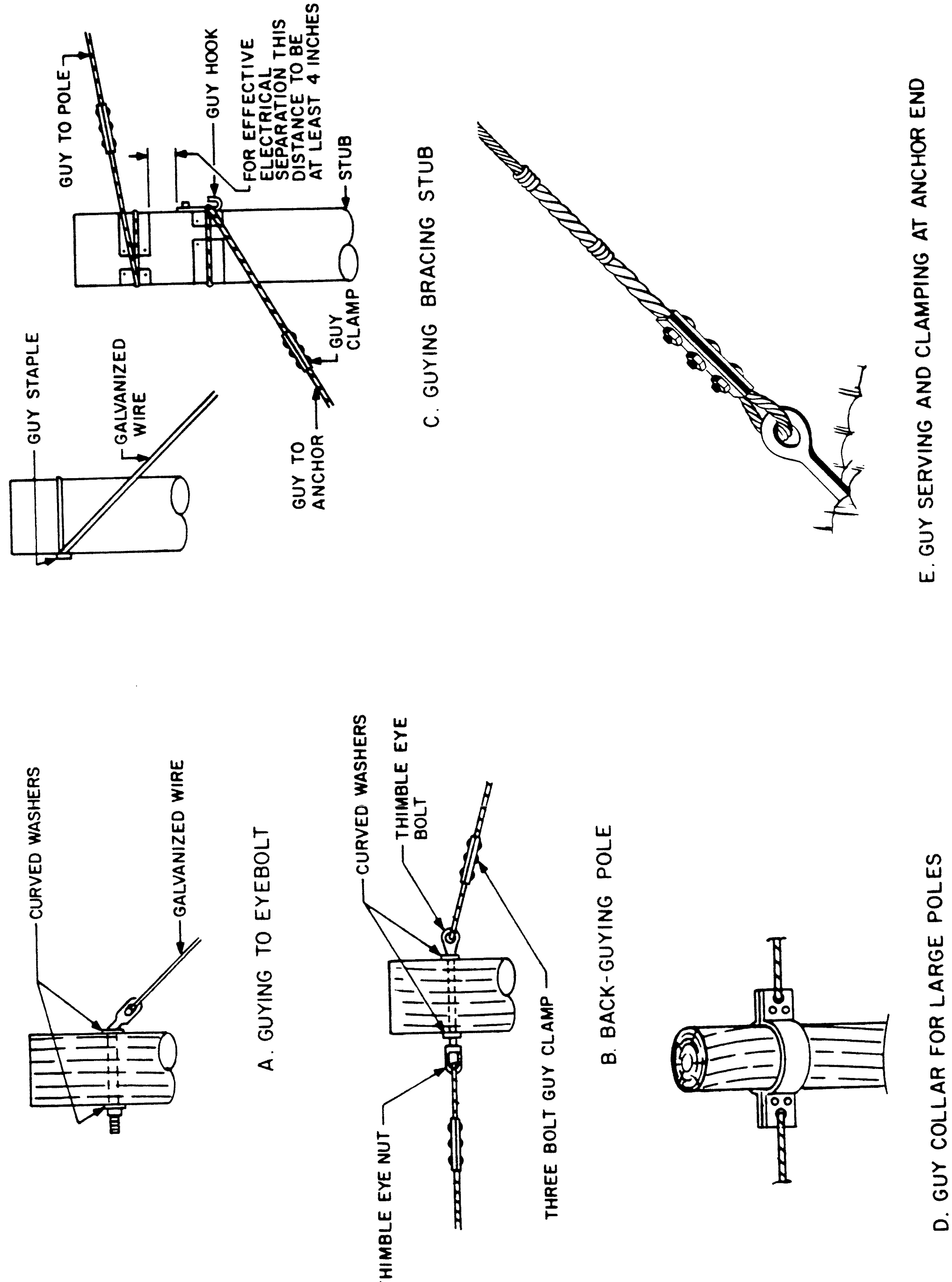
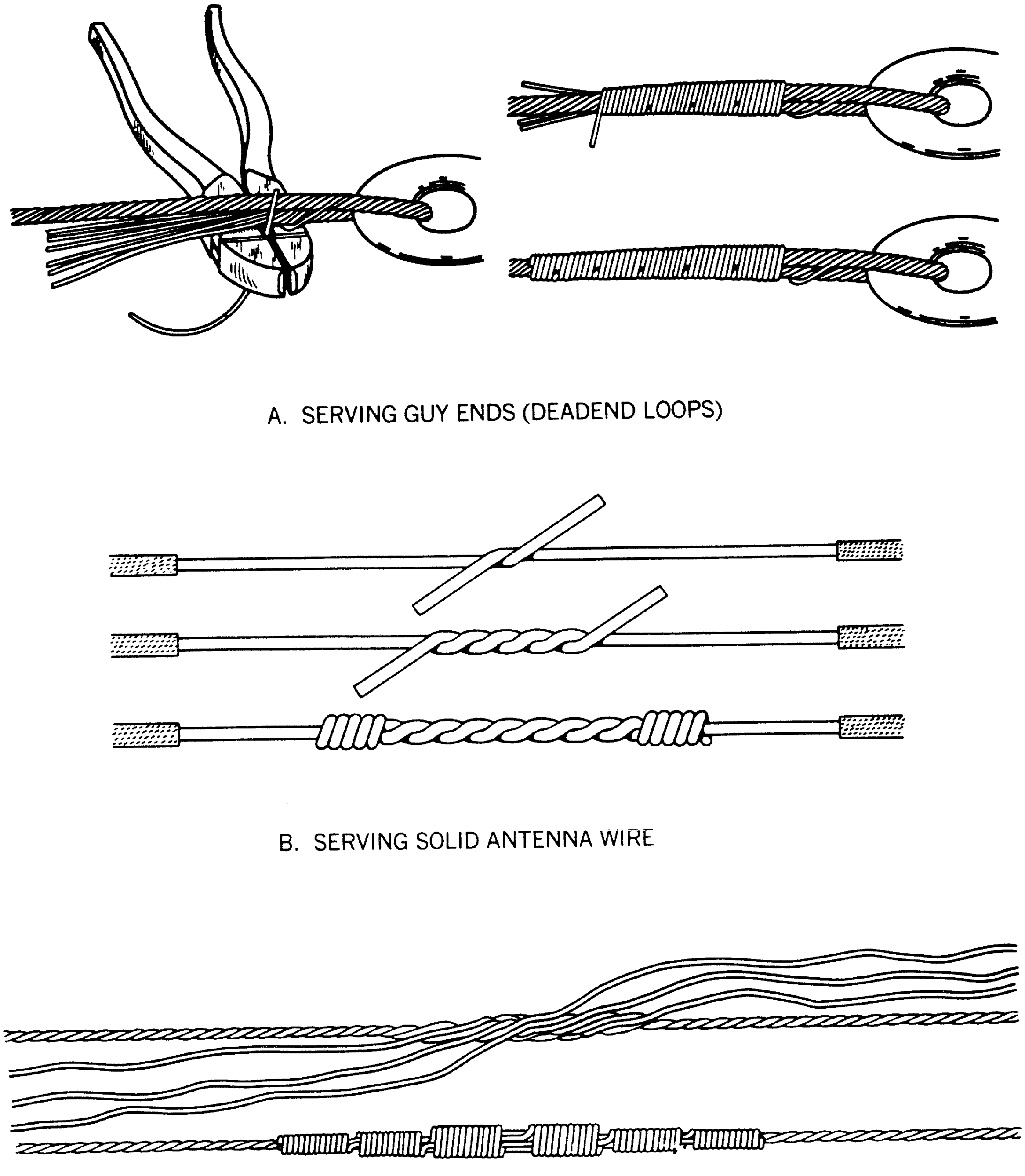


Figure 3. Guy Attachment



A. SERVING GUY ENDS (DEADEND LOOPS)

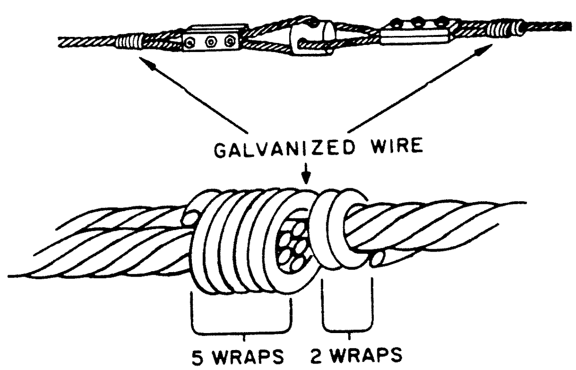
B. SERVING SOLID ANTENNA WIRE

C. SERVING STRANDED ANTENNA WIRE

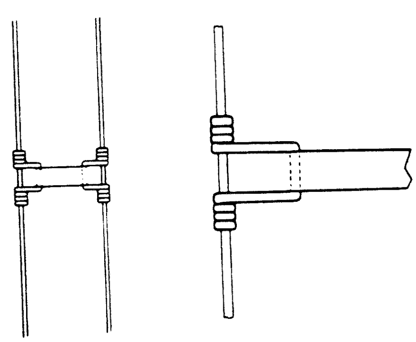
Figure 4. Serving Antenna Wire

ware. High-frequency antennas such as half-wave dipoles, vertical rhombics, or long-wire antennas require strain and spreader type insulators and the serving of the wire used in the antenna itself. Figure 4 shows proper serving of solid and stranded antenna wire. Figure 5 shows the tying of wire in the eyes of strain and spreader insulators. Figure 4 part A is a sketch showing the serving of a deadend loop, such as that installed at the pole eyebolt support of an antenna or the eye of an anchor rod. Figure 6 illustrates the installation of a simple half-wave dipole, complete with matching converter and fed at the center. A short pole is set at the center of the antenna to serve as a stabilizing support for the matching converter made of coaxial cable. Strain insulators are used to insulate the ends of the antenna (in a half-wave dipole, the ends are high-voltage points) and, at the center, to break the antenna into two sections driven by the feeder arrangement at the output of the converter. The inset of figure 6 provides an enlarged view of the method of connecting coaxial cable center conductor and outer shield to both sides of the antenna feed point.

A. SOLID-WIRE TIES FOR STRAIN INSULATOR



B. STRANDED TIES AND CLAMPS FOR STRAIN INSULATOR



C. TIES FOR SPREADER INSULATOR

Figure 5. Tying Strain and Spreader Insulators

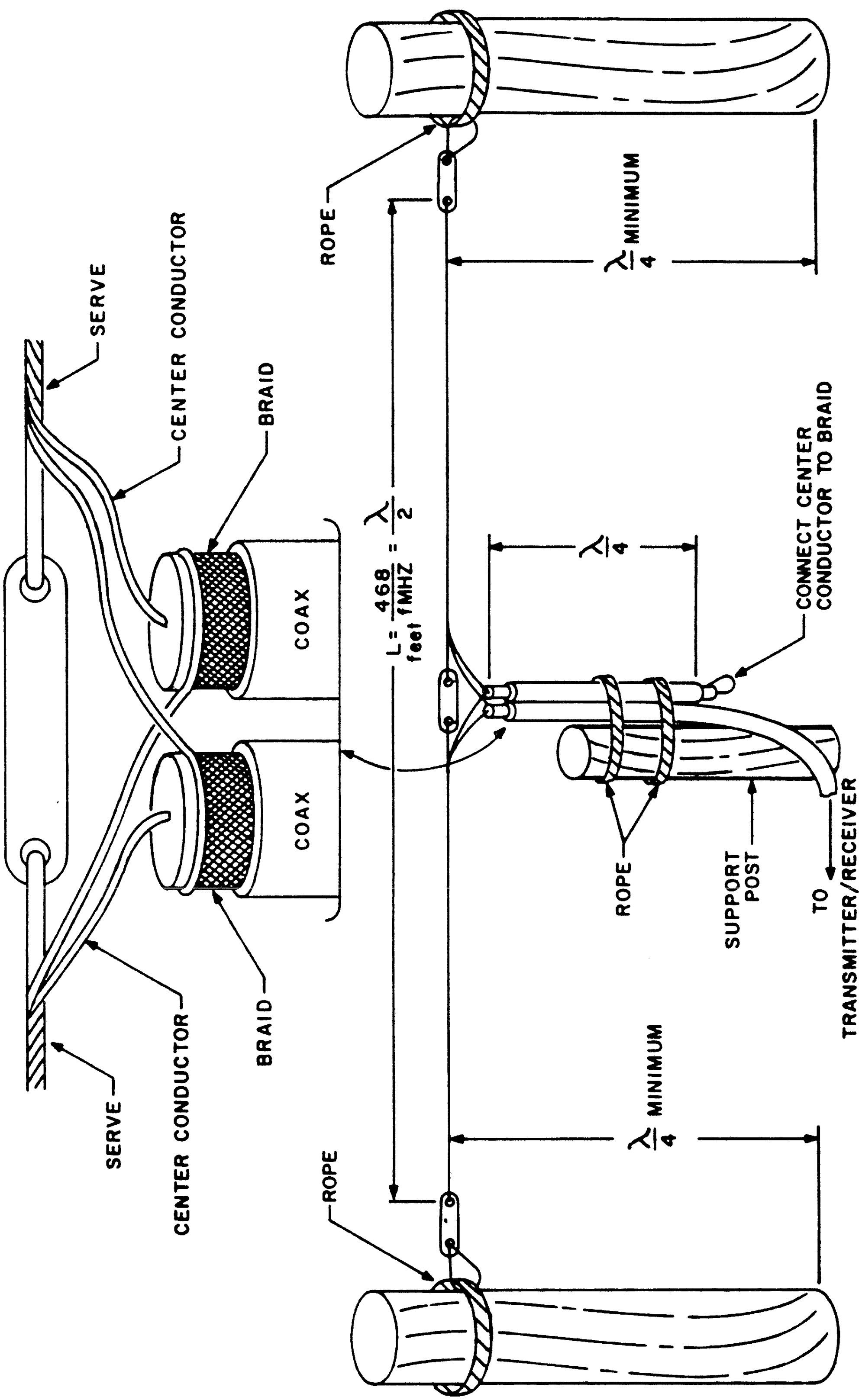


Figure 6. Typical Emergency Half-Wave Dipole and Feeder

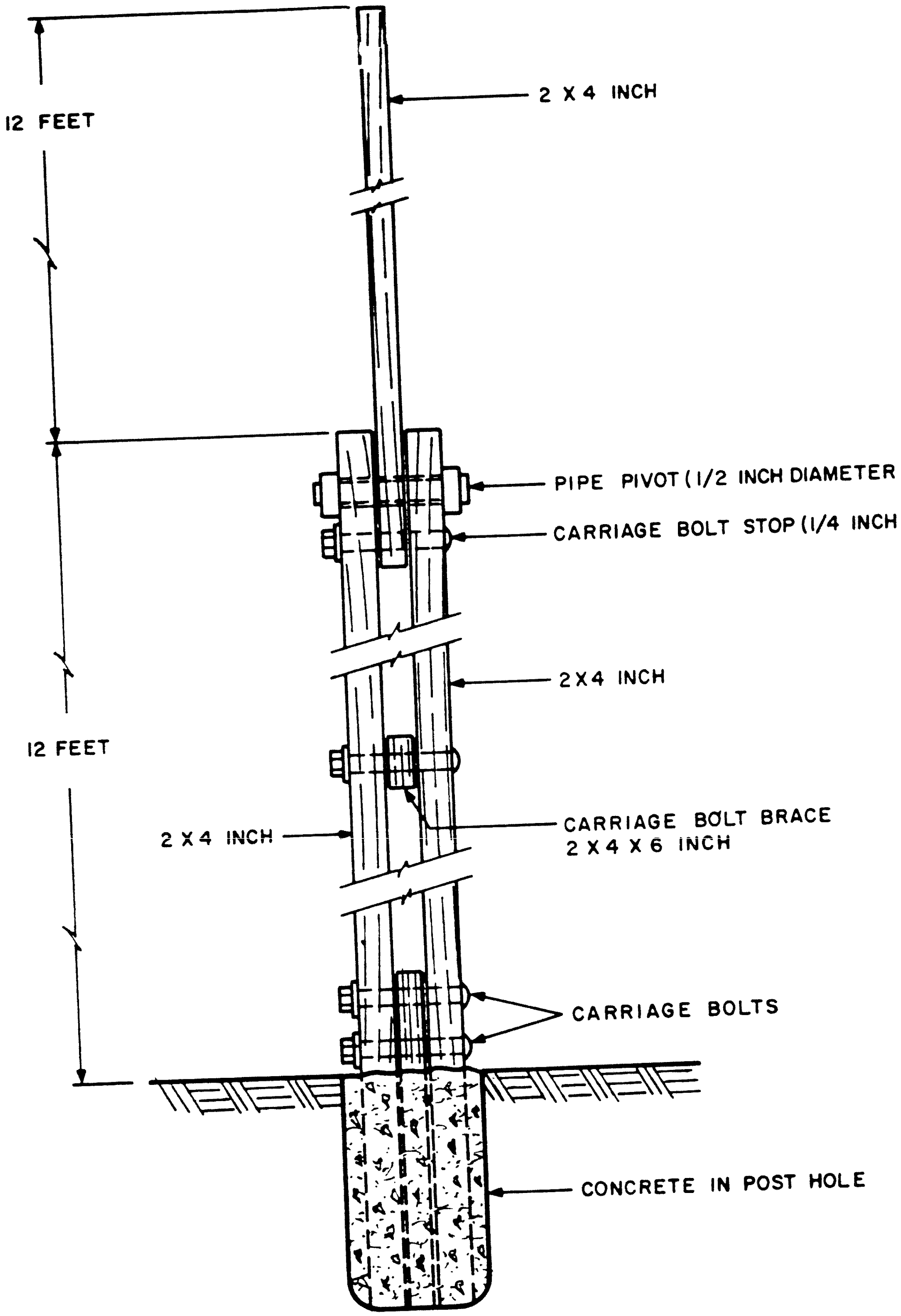


Figure 7. Folding Mast Antenna Support

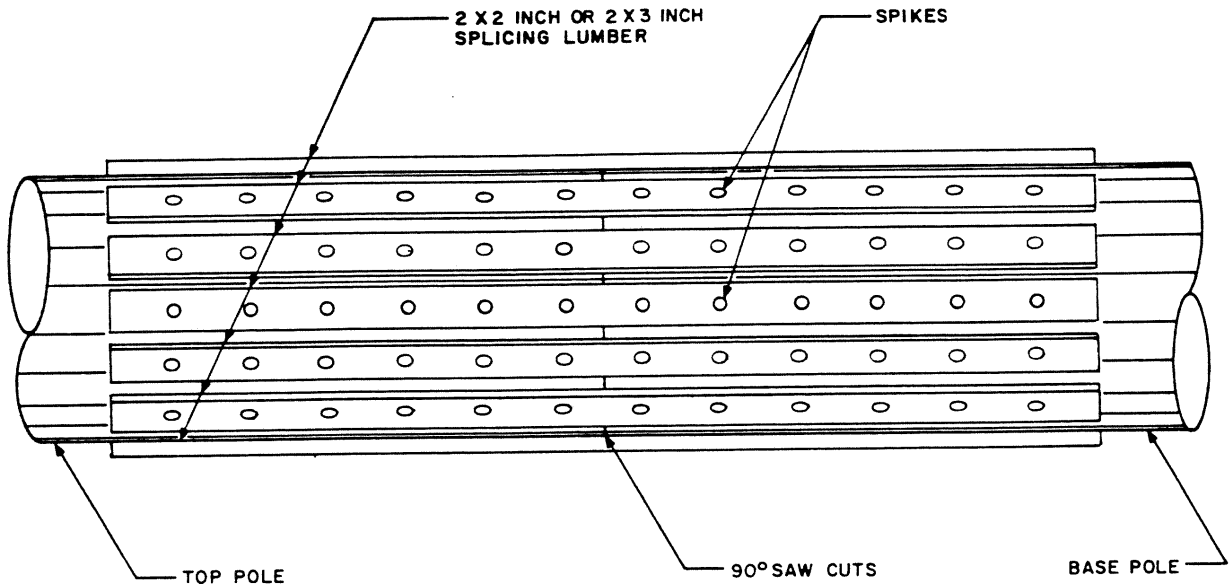


Figure 8. Example of Butt Splice for Poles

3. OTHER KINDS OF SUPPORTS.

Other than trees, utility poles (already installed), and poles obtained from various sources, supports can be fabricated from finished lumber. Light-duty receiving television masts can be obtained from television supply outlets and used provided that the antenna to be supported is not too heavy. Some fabricated supports are described below.

a. **Folding Mast.** A mast allowing raising and lowering the antenna for tuning or repair is the folding type shown in figure 7. This type is excellent for holding a simple vertical whip, discone, coaxial, swastika, or a J antenna.

b. **Extended Mast.** Extension of the height of an antenna can be obtained by butt-splicing lumber or poles. See figure 8.

c. **Supporting a Number of Antennas.** A four-corner tower and platform can be approximately duplicated by setting four wooden poles at the same height and constructing a wooden platform and railings. Pipe masts can be clamped on the railings and the communication antennas installed. Although the height above ground may be restricted in this temporary arrangement, complete or nearly complete operation can be resumed while the permanent tower is being repaired or replaced.

4.-9. RESERVED.

Section 2. EMERGENCY ANTENNA AND FEEDER FABRICATION

10. GENERAL.

This section includes temporary antenna structures made of wire and tubing, some using wooden members for maintaining their proper dimensions and shape.

11. HF ANTENNAS.

The three hf antennas most likely to serve in an emergency are the doublet or multiwire doublet, the inverted V (when a directive antenna is needed), and the long-wire antenna (for moderate directivity and fast construction). Construction details of each of these antennas are shown, respectively, in figures 9, 10, and 11. Dimensional information and formulas are provided in the figures or are located in appendix 3.

a. The multiwire receiving doublet antenna will operate over a relatively large band. It is constructed by paralleling two or more half-wave dipoles (each cut to its operating frequency) at the center feed point and feeding with coaxial cable type RG-11A/U or other 75-ohm cable. To assist broadbanding, the ends of the dipoles are fanned out, as shown in figure 9.

b. The inverted V antenna is easy to construct for use in the hf band. It has moderate directive properties. It is fed at the center with 50-ohm coaxial cable such as RG-213/U. The input impedance of the inverted V is lower than that of a half-wave dipole. A pole height of about 60 feet (18.2m) provides leg angles of 45° with an apex angle of 90°. Because this antenna functions best as a resonant antenna (for low swr), the ends of the legs should be left slightly longer than the length so that they can be cut (after erecting) for best transmitter loading at the operating frequency. See figure 10 for details.

c. The long-wire antenna is perhaps the fundamental directive antenna used on high frequencies. It is a fundamental component of the V and rhombic, which are long-wire arrays. It is usually driven with open-wire feeders, as shown in figure 11, and is fed at one end. The longwire antenna provides a basic clover-leaf horizontal directivity pattern. The azimuthal lobe positions change as the length is increased from a half wave to two and three wavelengths or more. Lobe maxima are at 50° from the 0° to 180° axis for a full wavelength long-wire antenna. They are at 30° from the axis for a two-wavelength antenna. To obtain the desired directivity, the antenna should be oriented by positioning its support poles of azimuth by the number of degrees for the lobe maxima of the antenna design.

12. VHF AND UHF ANTENNAS.

The vhf and uhf antennas most likely to serve in an emergency are the whip, vertical half-wave dipole, and the vertical J antenna. As air-ground communication is more efficient with vertical polarization than with horizontal polarization, it is advisable to construct the emergency antenna for that polarization. Figures 12, 13, and 14 provide construction details of the three antennas enumerated above. Figure 13 shows a vertically-polarized half-wave dipole that may be constructed and supported by a yardarm on a tree or mast. Dimensional information and formulas are provided in the figures or are located in the working data of appendix 3.

a. **The Whip Antenna.** The flexible version of the whip is also called the "limp" antenna. It can be hung from a branch of a tree, a yardarm, a mast, or any other convenient support. See figure 12.

(1) To construct this antenna, first make an X-frame from wood or other non-metallic material. Make it of a size that up to four turns of coaxial cable can be accommodated on a diameter of about 2 inches.

(2) Next, solder a length of wire to the center conductor pin of a coaxial connector plug that had previously been connected to the end of the transmission line. This is the whip radiator. The other end of this wire is passed through the eye of an insulator and fastened with a clamp as shown in figure 12. With this arrangement, the length of the whip can be adjusted to operate best on various frequencies. In all cases, the whip length, the distance between the coaxial conector plug and the top insulator must be 95 percent of the quarter wavelength at the frequency of operation. The length in inches is 2800/frequency in MHz. The length of the skirt (the section between the top of the coil and connector plug tip) should be 25 inches (63.5cm) for operation in the air-ground vhf band. The turns of the coil and lengths of skirt and whip can be varied for optimum transmitter loading at the frequency required.

b. **The Vertical Half-Wave Dipole.** Use a vertical piece of wood to support the antenna and a rigid metal tubing or rod for the antenna itself. See figure 13.

(1) Measure and cut the yard-arm length to about one-half the overall length of the antenna.

(2) Mount four standoff insulators on the upright as shown in figure 13 and attach two lengths of tubing to act as the antenna. For a half-wave antenna with 5 percent end effect, the formula is given in the figure.

(3) Drill the tubing so it can be mounted on the standoff insulators. Otherwise, improvise small clamps or tie the tubing to the insulators with wire.

(4) Solder a coaxial cable loop to the tubing as illustrated and tie or tape the line to the wooden yard-arm. Leave a slack loop in the downlead to prevent damage from too sharp a bend.

c. **The Vertical J Antenna.** This antenna, shown in figure 14, is also constructed of metal tubing or rod. Mount it with its matching stub without standoff insulators at the metallic strip–a ground at this point will not affect operation of the antenna. Use standard or improvised metal clamps at the points where the coaxial or other transmission line connects to the matching stub. Determine dimension Z so as to produce normal output loading of the transmitter.

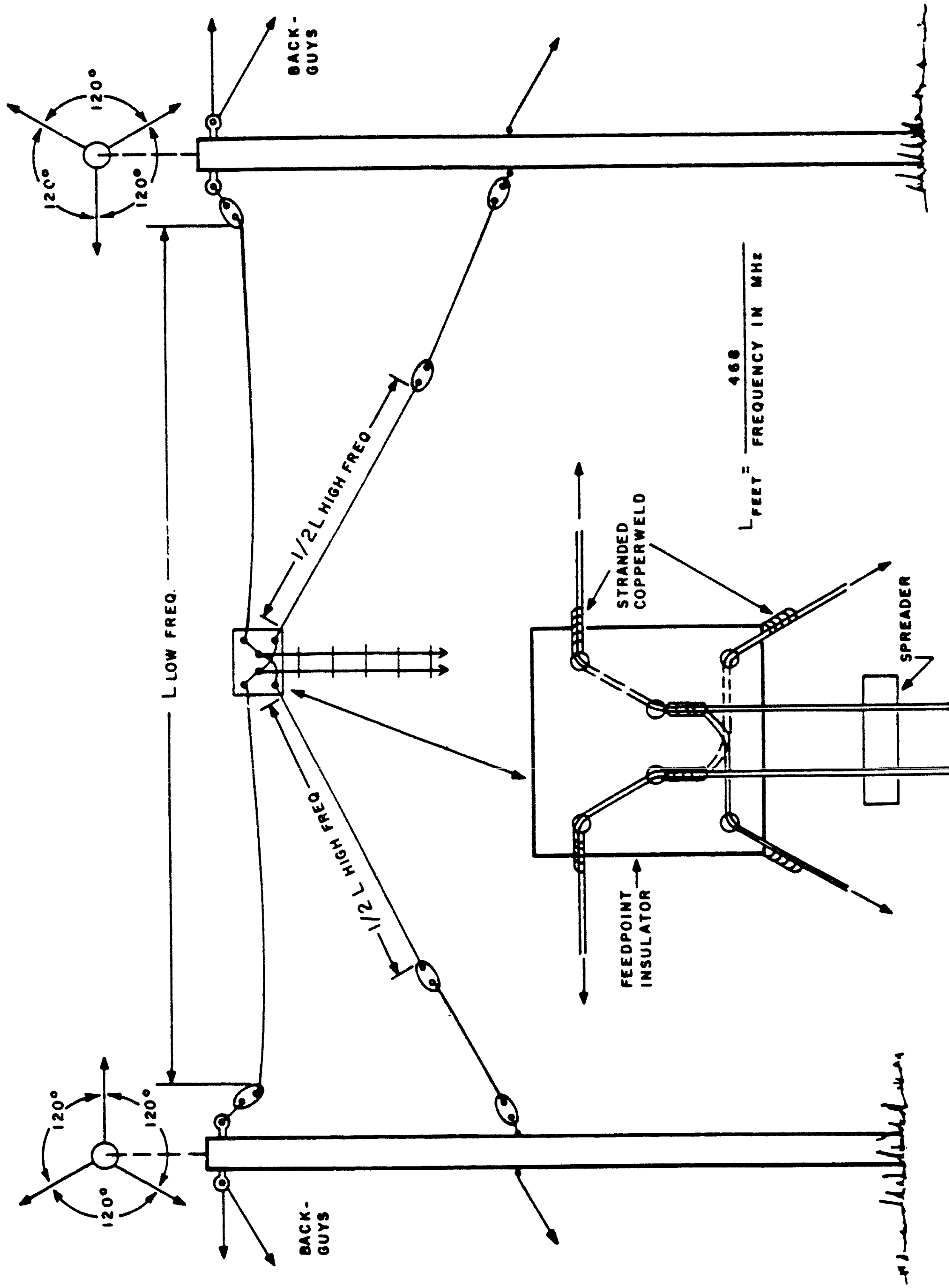
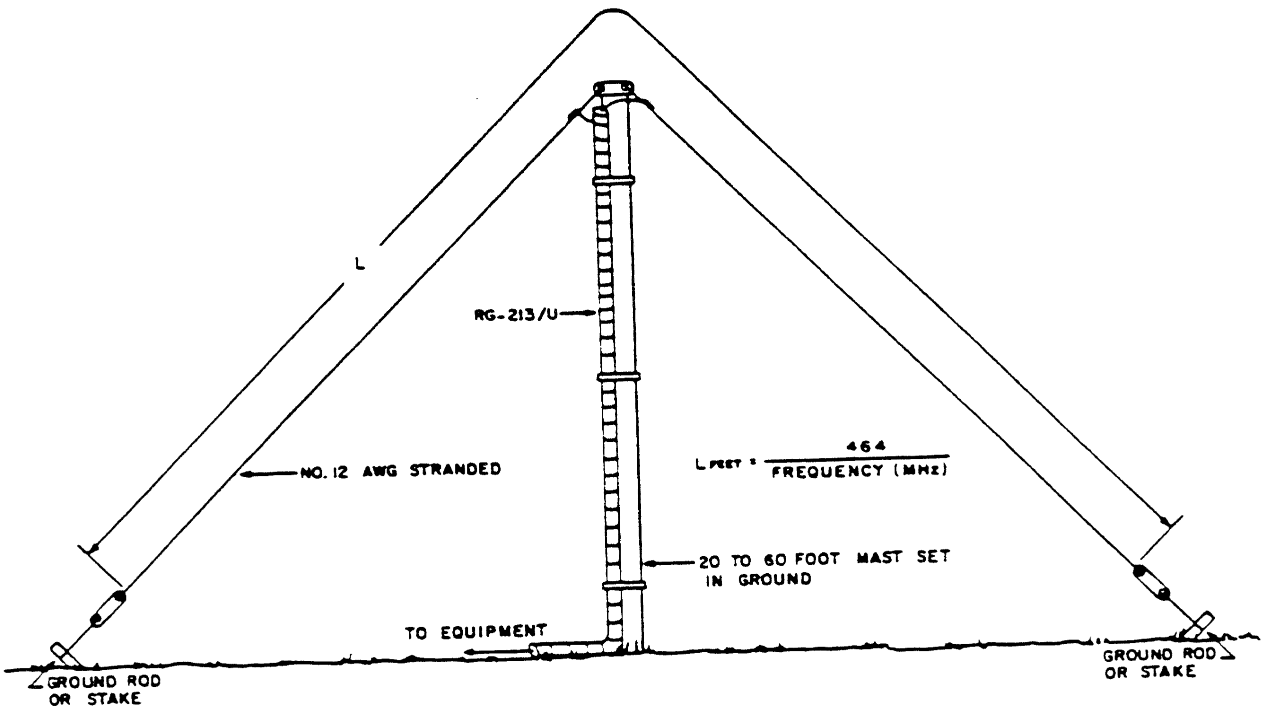
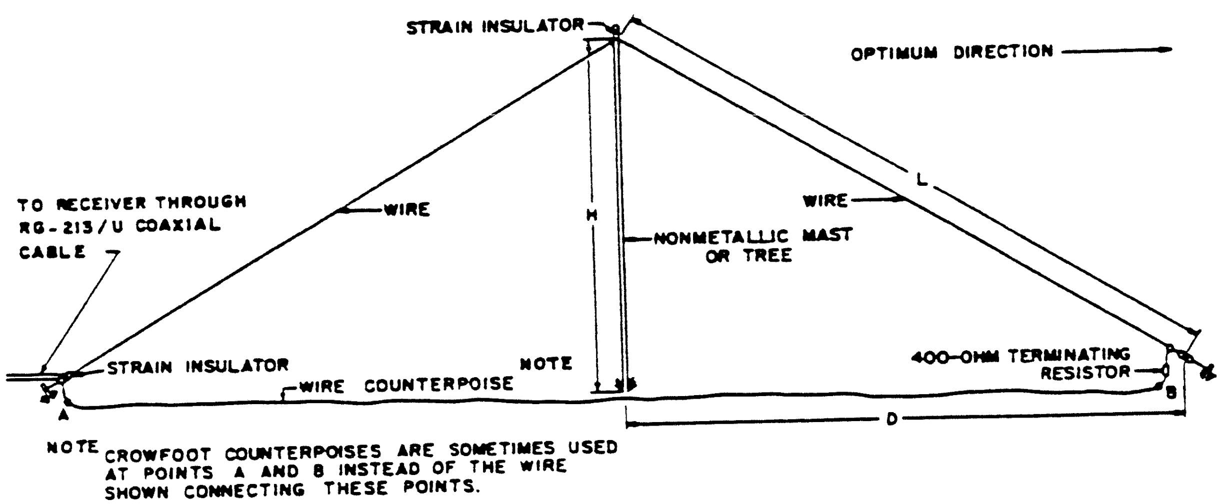


Figure 9. Multiwire Doublet Antenna



A. VERTICAL V ANTENNA



B. VERTICAL HALF-RHOMBIC ANTENNA

Figure 10. Vertical V and Half-Rhombic Antennas

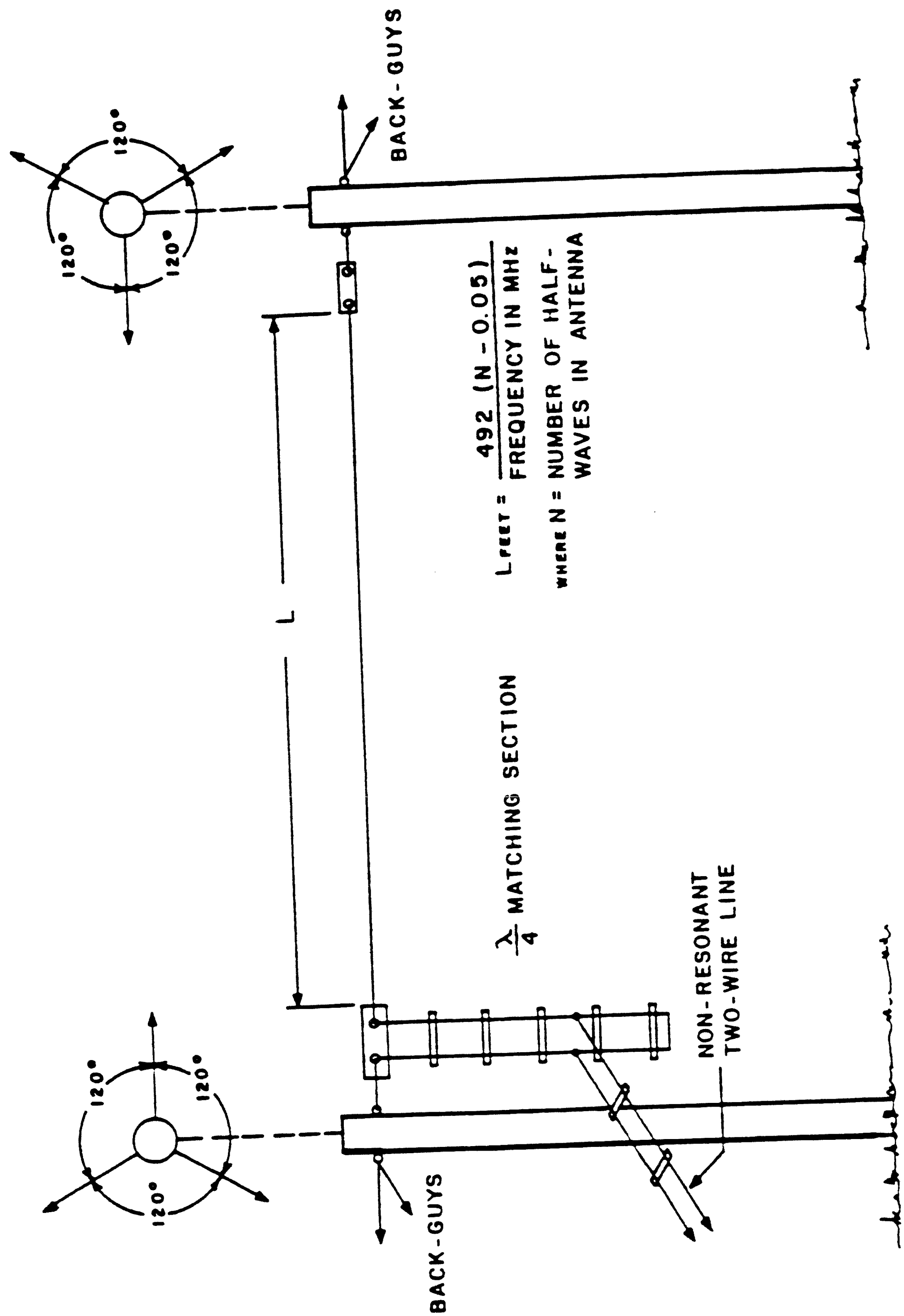


Figure 11. Long-Wire Antenna

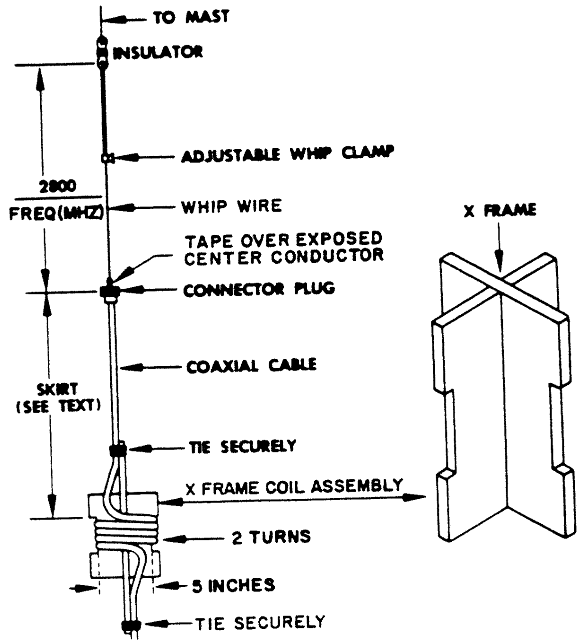


Figure 12. Whip Antenna

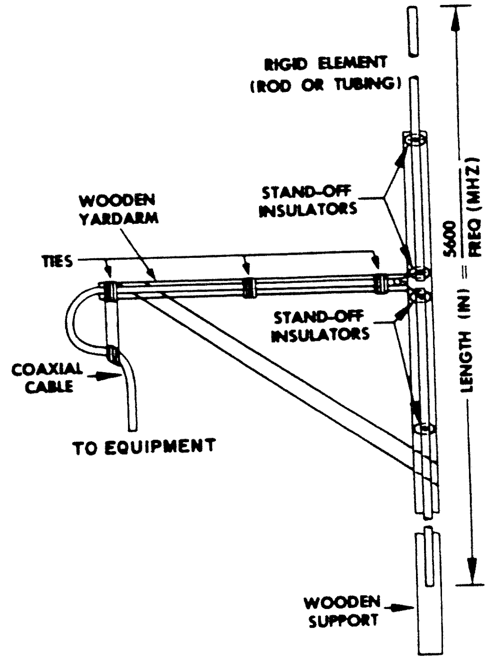


Figure 13. Vertical Half-Wave Dipole Antenna

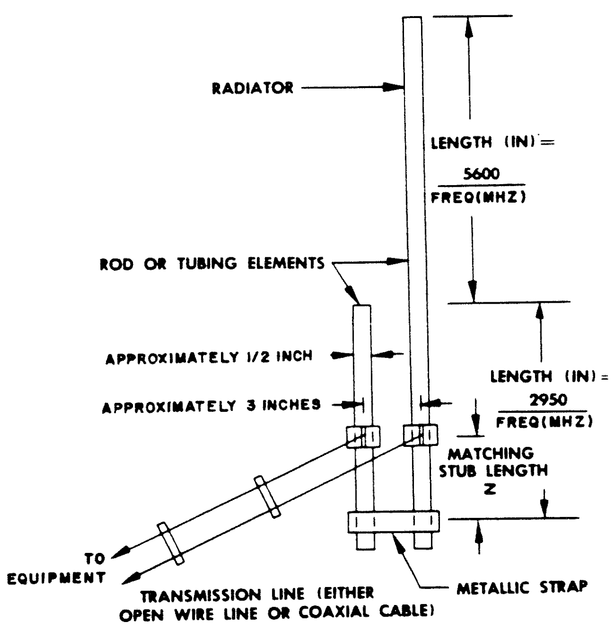


Figure 14. Vertical J Antenna

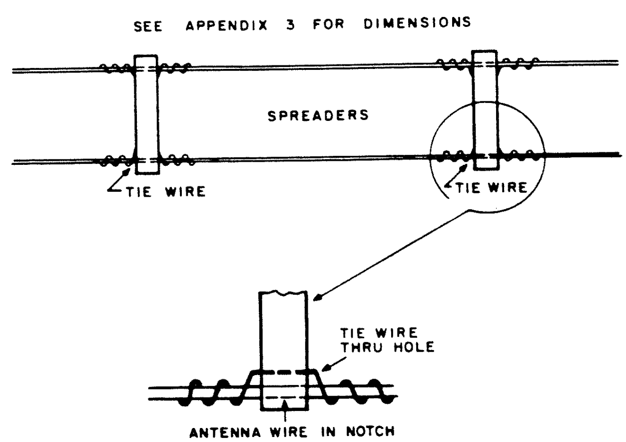


Figure 15. Open-Wire Line Construction

13. IMPROVISED FEEDERS.

a. If spare transmission lines are available, which are identical with or similar to that used in the original installation, use improved feeders as a last resort. If the transmission line has been broken, carefully repair the breaks with splices. Splice broken coaxial line if you do not have the proper coaxial fittings to make a good connection. Even with proper fittings, when it is important to set up an installation in a short time, use a simple splice rather than take the time to install the fittings. When an improvised antenna is located a considerable distance from a transmitter, connect several lengths of coaxial line together. Even if the lines do not have exactly the same characteristics (one may have a characteristic impedence of 70 ohms, the other may have one of 52 ohms), the mismatch may be small and the power lost due to mismatch would probably be considerably less than would occur with an improvised line.

b. Splicing rather than using the proper coaxial fitting introduces some discontinuity. However, here again the amount of loss would probably be less than if an improvised line were used. In splicing coaxial line, solder the two inner conductors together. Then wrap them with plastic or rubber tape. Next, connect the two outer braids together with a short piece of wire. Finally, tape the entire splice.

c. Since flexible coaxial line is of such a special prefabricated nature, it can very seldom be improvised. On the other hand, improvise an open-wire line by using any available wire and locally constructed spreaders. The nature of these spreaders will depend on what material is available. Small wooden strips, two to six inches (5 to 15 om) long, can serve as spreaders in an emergency. For attaching the spreader, use short tie wires tied to the ends of these spreaders and twisted around the wires, making up the transmission line. (See figure 15.) Fabricate spreaders from plastic, hard rubber, or any other nonconductor. Drill holes or attach clips at both ends so that the spreaders can be installed between the conductors.

d. In using an open-wire line, consider the difference in the characteristic impedance of the improvised line compared to that of the original line used with the equipment. Too great a change may necessitate improving the existing matching transformers or changeing the points of connection on the antenna and transmitter to accommodate the new impedance.

e. Ordinary electrical wire or television (tv) twin lead can be used to improvise a transmission line. When using tv twin lead as an rf transmission line, considerable loss will occur. When the line is wet, the losses are very high.

14. IMPROVISED MATCHING TRANSFORMERS.

Coaxial cable can be used as matching sections to be used directly at the feed point of an antenna. Figure 2-61 part A, cut a length of flexible coaxial line just 1 balanced antennas of relatively high impedance with low-impedance unbalanced cable.

a. To construct the arrangement shown in figure 2-16 part A, cut a length of flexible coaxial line just 1 inch (2.5om) longer than the required quarter wavelength. Remember to consider the reduced velocity of propagation, which is 0.66 for most coaxial lines of this sort. Remove about 0.75 inch (1.8cm) of the vinyl jacket at one end of the quarter-wave section. Using a pointed instrument, unbraid the exposed outer conductor. Then twist the unbraided strands together to form a pigtail connection. Next, remove 0.5 inch (1.2cm) of the dielectric material to expose the inner conductor. Carefully tin the inner conductor and the outer conductor pigtail in preparation for soldering. Remove 0.75 inch (1.8cm) of the vinyl jacket at the other end of the quarter-wave section, and remove 0.5 inch (1.2cm) of the braid and dielectric to expose the inner conductor. Now solder the inner conductor to the outer conductor to form the shorted end of the section. Next, solder the 0.5 inch (1.2cm) of tinned inner conductor at the other end to the outer conducter of the coaxial transmission line. Finally, solder the outer conductor of the quarter-wave section to the inner conductor of the coaxial transmission line. This completes the construction shown in part A of figure 2-61.

b. In the arrangement shown at figure 2-61, part B, the dielectric for the quarter-wave section is mainly air. This is true because the shorted section of coaxial line acts as one conductor of a two-wire line in conjunction with the outer conductor of the main coaxial line. The velocity of propagation for this section is 0.95. To construct this converter, use a quarter wavelength coaxial line with the inner and outer conductors shorted together at both ends. Connect one end of this length to the inner conductor of the coaxial transmission line at the point where it is connected to the antenna. Connect the other end of the shorted length to the outer conductor of the main coaxial line as shown. In order to make this connection, it is necessary to remove a small amount of the vinyl jacket of the main coaxial line. Maintain an air space of about ½ to 1 inch (1.2 to 2.5cm) between the additional section and the main transmission line.

c. In the arrangement shown at figure 2-61, part C, an electrical half wavelength of coaxial line is doubled back on itself. The outer braids of the half wavelength section and of the main coaxial line are all soldered together at the ends. The inner conductor at one end of the half-wave section is soldered to the inner conductor of the main transmission line, and both these conductors are connected to one side of the antenna. Finally, the inner conductor at the other end of the half wavelength section is connected to the other side of the antenna as illustrated. This system is used to convert the low impedance of an unbalanced line to the high impedance of a balanced load, and it produces a match of 4 to 1. For example, if the unbalanced impedance of the coaxial line is 75 ohms, then the balanced impedance is 300 ohms.

APPENDIX 10. CONNECTING ADDITIONAL RECEIVERS TO A SINGLE ANTENNA

1. GENERAL.

This appendix discusses methods for multipling receivers to an antenna. Techniques used for high-frequency (hf) operation differ from those applicable to frequencies above 30MHz. Methods of multipling receivers also differ if the receivers are of balanced radio frequency (rf) input instead of unbalanced input. These differences are explained in the following paragraphs. The simplest multipling methods connect the receivers in series with, or in parallel across, the antenna feeders. Multicouplers are single-input to multiple-output isolation devices, either passive or active. Depending on application, they may be in either balanced rf or unbalanced rf form. In all multipling arrangements that do not use amplifiers to make up losses, a degree of rf signal loss is to be expected on each channel involved. However, there may not be a loss in signal-to-noise ratio in the detected audio of the receiver outputs.

2. MULTIPLING OF HF RECEIVERS ON ONE ANTENNA.

A single broadband antenna, such as the rhombic or the wave, can be used by several receivers tuned to different frequencies. The receivers should be divided into directional groups, with a separate antenna for each group and with individual antennas for those receivers that cannot be efficiently grouped. When several receivers, tuned to different frequencies, are connected to the same antenna without a common preamplifier (multicoupler), reduction in the signal voltage delivered to each receiver must be expected. Such reductions do not necessarily lower the audio signal-to-noise ratio. At times when the hf noise is high, considerable loss can be tolerated before receiver set noise becomes an important factor. However, any large reduction in signal voltage would be likely to reduce the percentage of usable circuit time over a 24-hour period. When a multicoupler is used, its load-carrying capacity for all signals received (both wanted and unwanted) is important. When the load capacity is too small, interference is produced by intermodulation of the various signals in the preamplifier.

3. METHODS OF COUPLING BALANCED-INPUT RECEIVERS ON ONE ANTENNA.

a. **Receivers in Parallel or Series.** When the input circuit of a receiver is tuned by antiresonance, its input impedance normally is higher at the operating frequency than at other frequencies. This higher impedance makes the series connection of receivers preferable, provided that receivers with balanced inputs are used. For example, assume two receivers U_1 and U_2 are tuned to materially different frequencies f_1 and f_2, respectively, and are connected in parallel. Then, at operating frequency f_1, receiver U_2 would be a low impedance and would tend to short out receiver U_1. Assume, conversely, that they are in series. Then, at the operating frequency f_1, receiver U_2 would drop only a little of the available f_1 voltage, leaving most of it for the operation of receiver U_1.

(1) With balanced-input receivers located close together and connected in series, up to four or five receivers tuned to different frequencies may be used before the losses exceed 10 to 15dB - compared with a matched-impedance condition.

(2) The use of more than two or three receivers in parallel, tuned to different frequencies, usually results in large losses.

(3) When several receivers are connected to one antenna, interference may be produced in any one of them by spurious outputs from the others.

b. **Multicouplers.**

(1) A multicoupler is a broadband preamplifier with multiple outlets, used to distribute signals to several receivers. A multicoupler reduces or eliminates the effects of spurious receiver outputs and the loss that occurs when the receivers are connected directly to the antenna or transmission line. However, since a multicoupler has a limited load capacity and a broad frequency band, strong unwanted signals such as those

from nearby transmitters can produce interference by intermodulation.

(2) One type of antenna coupler, operating in the range of 4 to 24MHz, is designed to allow operation of up to 10 receivers from a single antenna. Nominal input impedances are 75 ohms unbalanced or 150 or 600 ohms balanced. A spurious response (caused by intermodulation in the coupler) of less than 2μV will be produced fMHz away from either of two unwanted 5,000μV signals fMHz apart, if f is at least 2MHz. Restriction of unwanted signals to 5,000μV may necessitate considerable separation from any transmitting antenna. If f is less than 2MHz, the spurious response is larger.

c. Reactive Coupling Networks. Another method of coupling that avoids the intermodulation of the multicoupler and reduces effects of spurious receiver outputs. This method parallels all receivers across the common antenna or transmission line after first inserting a series-connected fixed inductor and variable capacitor into one of the leads to each receiver. The reactance of the whole series circuit formed by the inductor, capacitor, receiver, and antenna system impedance is tuned out at the operating frequency of the particular receiver. This method reduces the loss caused by multipling and produces a maximum signal voltage across each receiver. By this method, 5 to 10 receivers may be multipled without excessive loss because no standard equipment for this method is available, these networks should be designed and installed only by qualified personnel. The tuning adjustments of the individual series circuits are not entirely independent of each other when bridged across a common antenna. Therefore, after initial adjustments or whenever any operating frequency is changed, the tuning should be checked two or three times to insure good adjustments of all networks for the particular set of operating frequencies.

d. Resistive Coupling Networks. If a resistor is used in one antenna lead of paralleled receivers, the loss in signal is increased and the isolation of the receivers from each other is decreased in comparison with the reactive coupling system. The best value for the isolating resistor is $(n - 1) AB$, where n is the number of paralleled receivers, A is the antenna impedance, and B is the receiver input impedance. For a small number of paralleled receivers, the loss between receiver inputs is too small to control an ordinary spurious receiver output that coincides in frequency with a weak wanted signal. If the resistor value is made larger, this loss increases, but the loss in the wanted signal also increases. Thus, resistive coupling networks for feeding a number of receivers from the same antenna have a restricted field of use.

4. MULTIPLING VHF UNBALANCED-INPUT RECEIVERS ON ONE ANTENNA.

Very-high-frequency (vhf) receivers can be series multipled on a single antenna by the use of jumper coaxial cables if the channel frequencies are at least 1MHz apart. As many as five receivers can be so connected by 24.5-inch (62.2cm) cable lengths; however a maximum of three receivers is preferred. For installations where the 24.5-inch length is too short, an additional section 32¾ inches (82.2cm) long (or multiples thereof) may be added to the 24.5-inch (62.2cm) length. Refer to TI 6620.2A, Instruction Book, Receiver Radio, AN/GRR-23 and AN/GRR-24, Volume 1, paragraph 3.4, for operation of two solid-state VHF or UHF receivers from a single antenna.

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